• Volume 7G, Number 1, January 1958

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Section G
GEO-SCIENCES

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ON THE LITHOSTRATIGRAPHY AND TECTONICS OF THE CARMEL

L. PICARD AND E. KASHAI *

Department of Geology,

The Hebrew University of Jerusalem

ABSTRACT

A historical review on the stratigraphical research of the Carmel and of Picard's various investigations in the northeastern Carmel between 1928 and 1940 are given. The lithostratigraphic results of the geological survey of Kashai carried out in 1955 on behalf of the Israel Continental Oil Co.** and a summary of the lithostratigraphic sequences are presented. A concept on the structure of the region is discussed. The reader is referred to the geological sheet "Zikhron Yaaqov" (1 : 100,000, Picard 1956). This map already contains the principal lithostratigraphic units and tectonic features of the northeastern, eastern and southern Carmel, incorporating E. Kashai's geological map 1 : 20,000 which comprises the area of the triangle Benyamina-Yoqneam-Yagur. Most recent paleontological research demands an age revision of the Mid-Upper Cenomanian indicated as ce_3, ce_4 on the government geological map. Accordingly ce_3, ce_4 of the government map has now been largely assigned to the Turonian. We have, therefore in the attached geological map (fig. 1.) divided the Turonian into three parts ce_3 —t_1, t_2, t_3 and the Cenomanian into two parts ce_1, ce_2.

PREVIOUS STRATIGRAPHIC RESEARCH (L. PICARD)

The geological knowledge of the Carmel up to the first world war was compiled by Blanckenhorn in his geological map (1912) and treatise (1914). Blanckenhorn attributed the prevalent chalky formations of the northern heights of the Carmel to the Senonian and the subjacent dolomitic beds to the Turonian-Cenomanian.

In 1926 and 1928, Picard investigated the region of the assumed Senonian and Turonian and found the chalky formations to belong definitely to the Cenomanian. He ascribed the 350 metres of dolomitic strata following below to the Lower Cenomanian-Vraconnian.

Continuing the survey in 1935 near Yagur (on behalf of the Nesher Cement Company), Picard found coarse dolomitic limestone but principally marble-like rudist reef limestone overlying the chalk series. These dolomite and reef limestone

* The work in this paper carried out by E. Kashai will provide the basis for a Ph. D. Thesis at the Hebrew University of Jerusalem.

** We are grateful to the Israel Continental Oil Company for permission to publish these results.

Received June 20, 1957.

(Meleke) beds were referred in 1940 (p. 12) to the "Upper Cenomanian" and tentatively compared with the Mizzi Yahudi-Ahmar horizon of the Jerusalem section.

In the same publication the senior author arrived at the following three-divisional stratigraphy of the northern Carmel: Main Dolomite or Lower Cenomanian, Chalk (occasionally with flint) series or Middle Cenomanian, Meleke-Dolomite series or Upper Cenomanian. Two cross-sections cutting the northwestern Carmel at Yagur and Haifa (Picard 1940, Figures 3, 4; see also discussion on "Meleke" 1938, p. 11) illustrating this view.

A similar division made by Blake in 1936 places the chalk-flint series in the Upper Cenomanian I. Blake did not distinguish a Middle Cenomanian in the Carmel although on his geological map this formation is widely distributed in Judea, corresponding there to Picard's Moza marl and horizons 11,12 (1938, p.4).

Additional investigations in 1936 and in 1940* (again for the Nesher Cement Company) revised some of our earlier thickness figures and provided details on the lithostratigraphy of the chalky series.

In April 1954 at the annual field meeting of the Geological Association of Israel the senior author's results on the stratigraphy of the northwestern Carmel were summarized and illustrated in the following cross-sectional sketch (Figure 2).

This sketch gives also the more important list of fauna undoubtedly belonging to the localities of the country richest in Cenomanian megafossils.

Another specific feature of the Carmel is the frequent occurrence of volcanic material. The Cretaceous volcanics were first described from the southern Carmel by Blanckenhorn (1914) who considered them as the "Liegende des Turonen Acteonellen-kalkes oder des Cenomans". According to Vroman (1938), the stratigraphic position is Upper Cenomanian. On Blake's maps the volcanic series is placed mostly between Cenomanian I and II. In the Wadi esh-Shelale** district, Picard (1940, p.12) found volcanic tuffs widely distributed in the lower part of the chalk series. At Beth Oren they were so rich in thin Ostrea shells that little doubt remained to him as to their marine depositional origin.

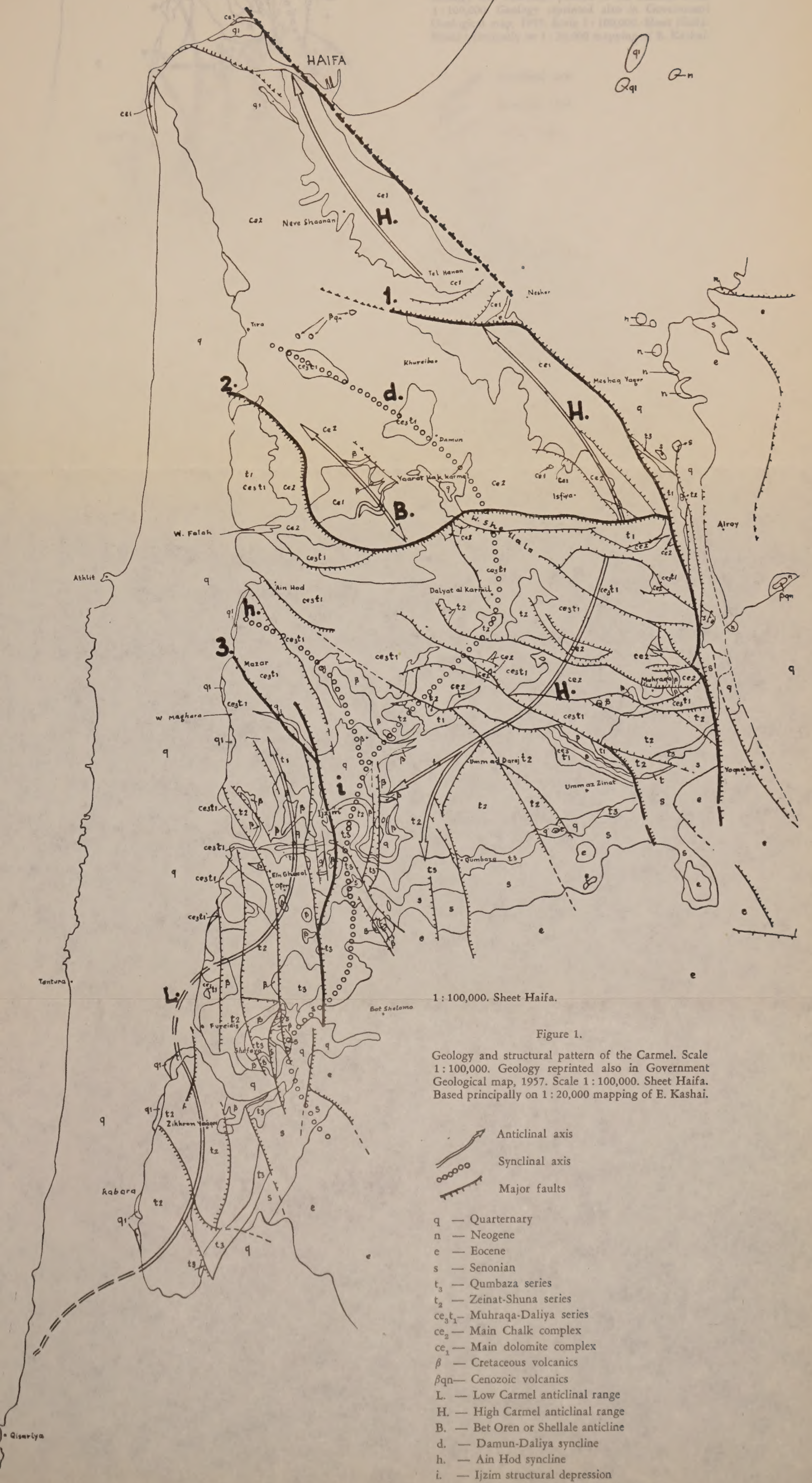
It, therefore, became more and more obvious that the volcanic series were intercalated in various marine Cenomanian horizons starting from the base of the chalk series up to the base of the Turonian.

Our main attention was directed, however, to the lithostratigraphy of the chalk series revealing the following sequences:

1. The lower and more marly part of the chalk series contains a distinct 15 metres thick falaise of Meleke. Sometimes a second but very thin Meleke bed lies a few metres underneath the falaise. Connected with and also replacing these Me-

* During the 1940 surveys the writer was assisted by Y. Bentor and Y. Zur.

** All geographical names are taken from the 1 : 20,000 mandatory maps, as the recent maps of the Survey of Israel are not yet fully available for general use.



1 : 100,000. Sheet Haifa.

Figure 1.

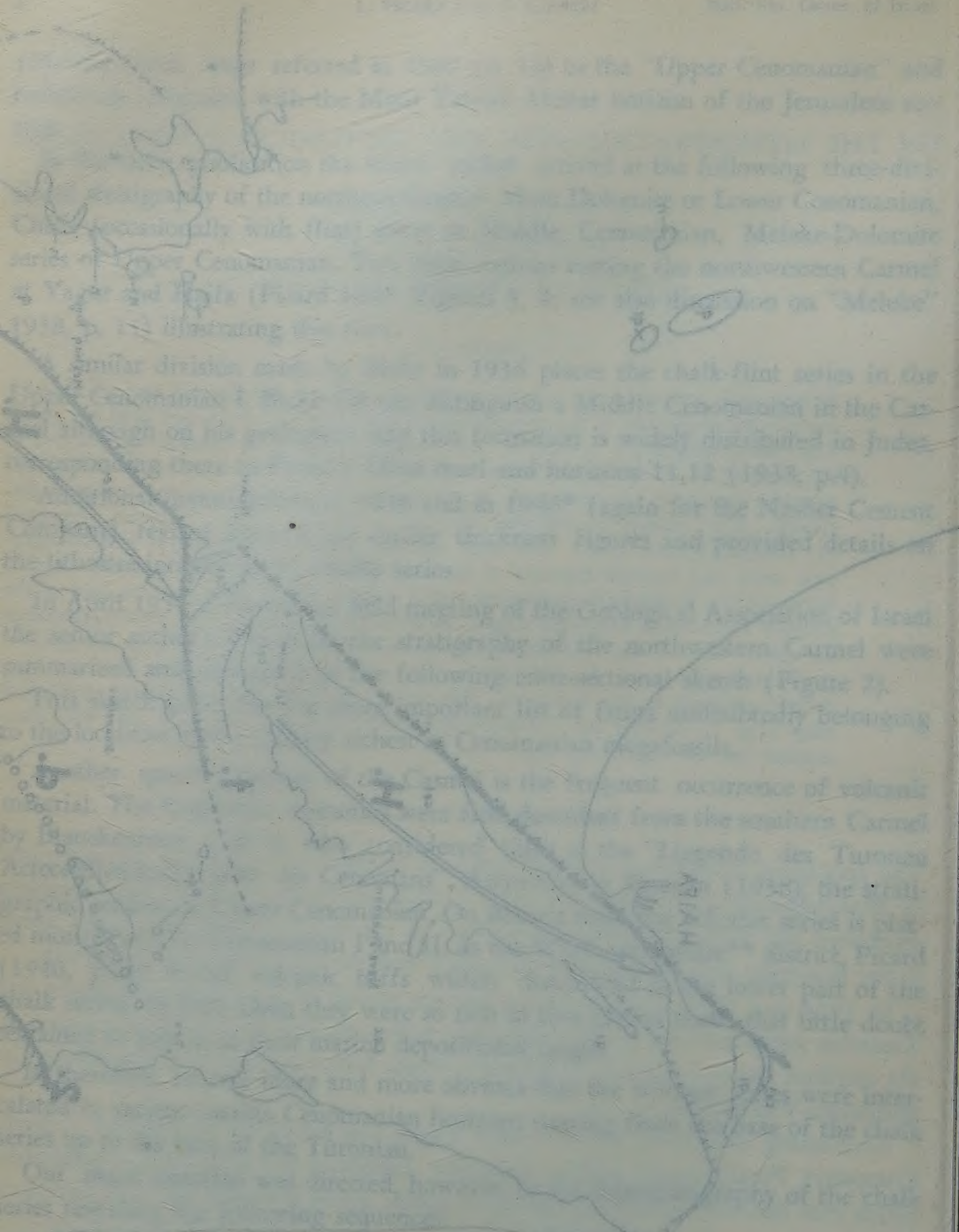
Geology and structural pattern of the Carmel. Scale 1 : 100,000. Geology reprinted also in Government Geological map, 1957. Scale 1 : 100,000. Sheet Haifa. Based principally on 1 : 20,000 mapping of E. Kashai.

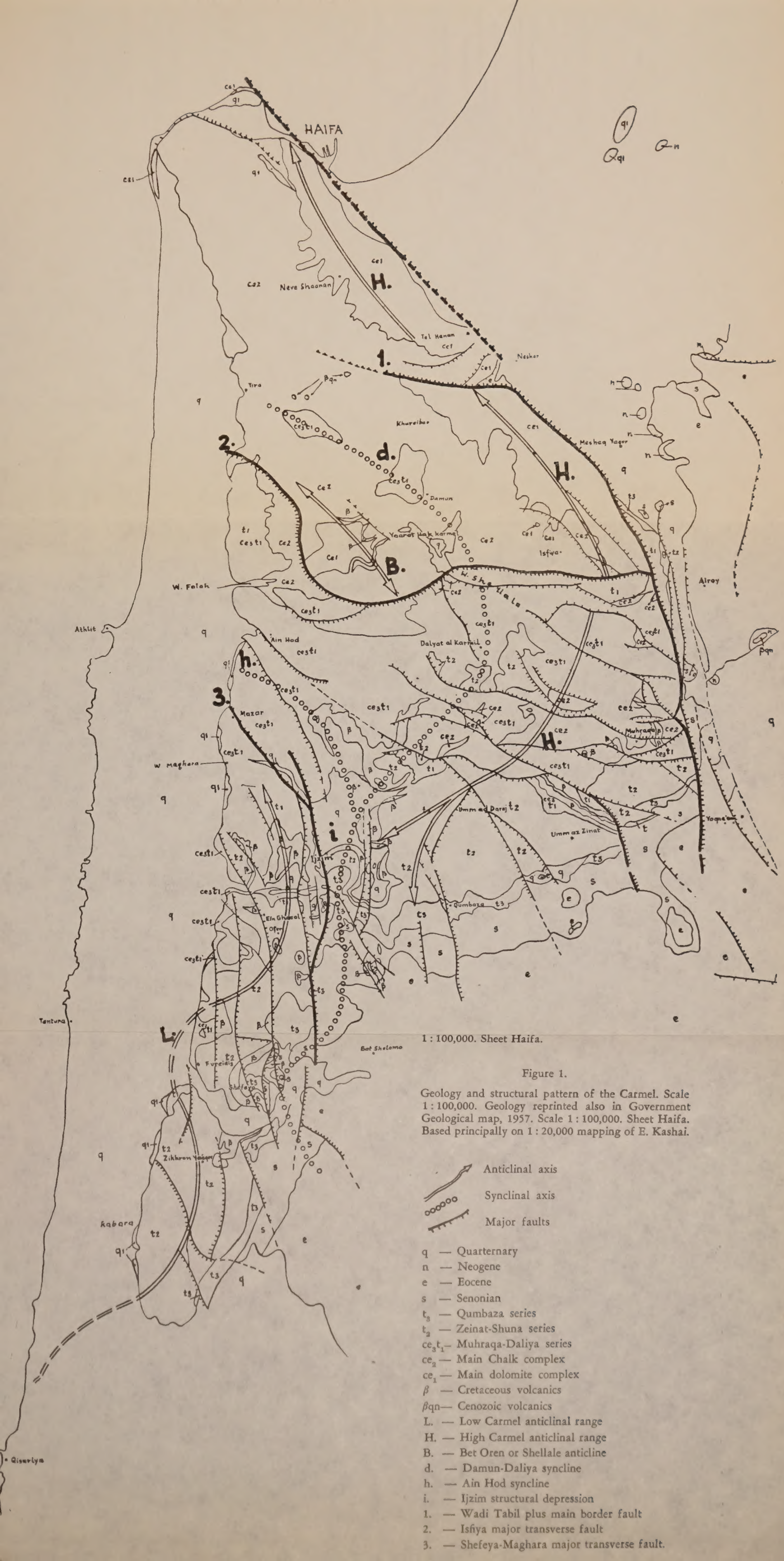
Anticlinal axis

Synclinal axis

Major faults

q — Quarternary
n — Neogene
e — Eocene
s — Senonian
t_3 — Qumbaza series
t_2 — Zeinat-Shuna series
ce_3t_1 — Muhraqa-Daliya series
ce_2 — Main Chalk complex
ce_1 — Main dolomite complex
β — Cretaceous volcanics
βqn — Cenozoic volcanics
L. — Low Carmel anticlinal range
H. — High Carmel anticlinal range
B. — Bet Oren or Shellale anticline
d. — Damun-Daliya syncline
h. — Ain Hod syncline
i. — Ijzim structural depression
1. — Wadi Tabil plus main border fault
2. — Isfiya major transverse fault
3. — Shefeya-Maghara major transverse fault.





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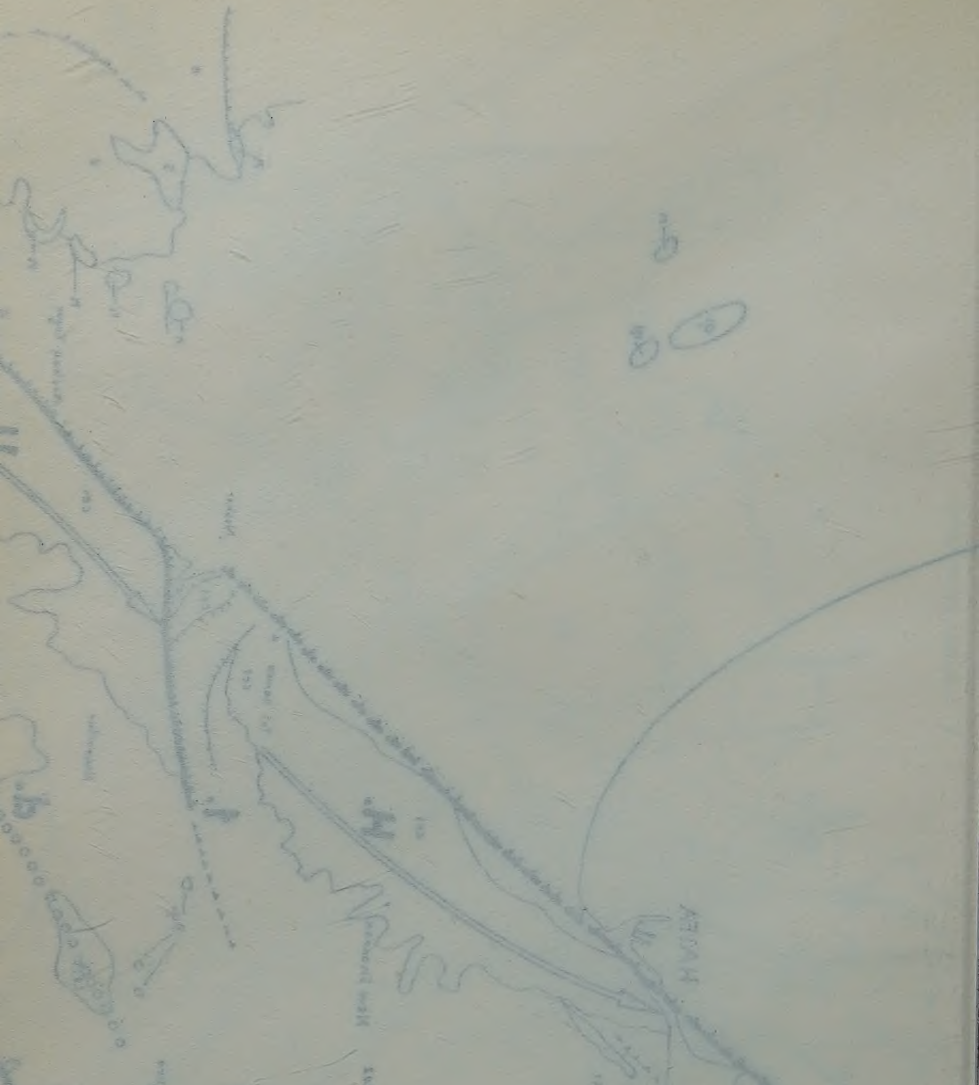

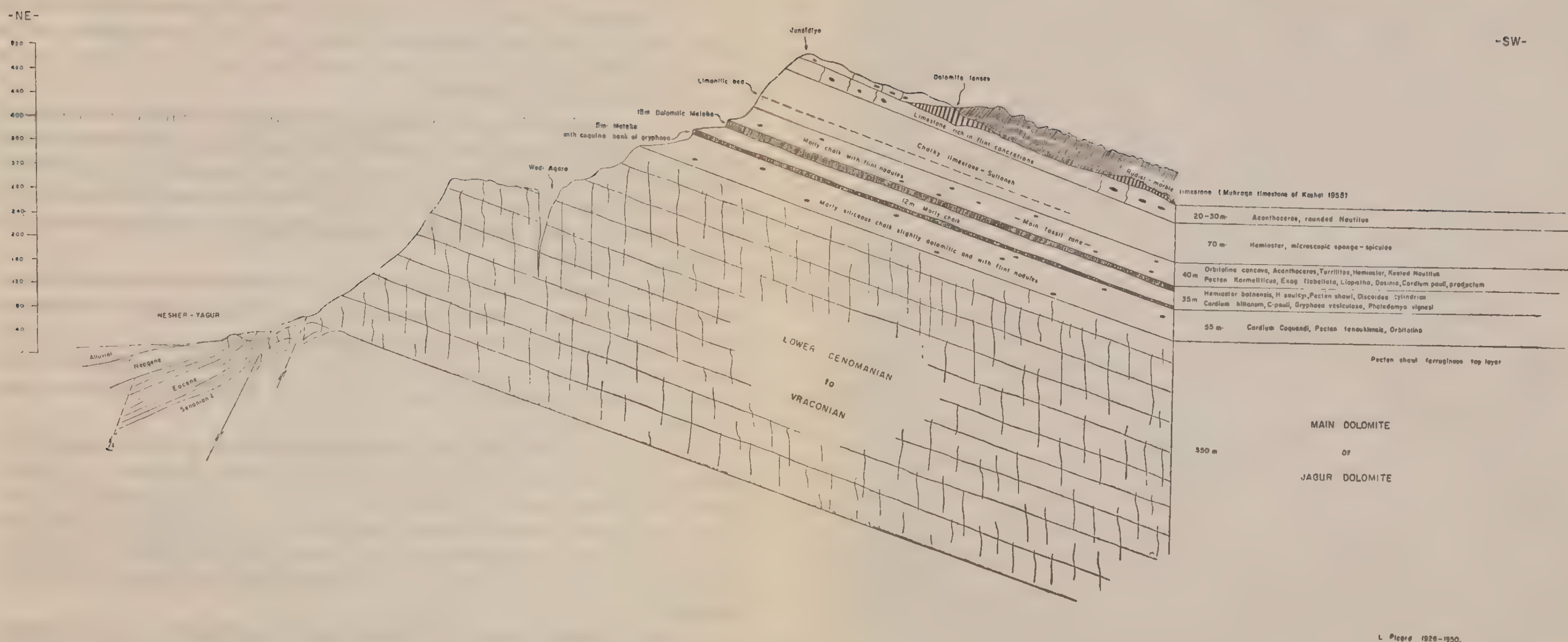

Figure 2.

Cross-sectional sketch on the stratigraphy of the northwestern Carmel near Nesher-Yagur by L. Picard.

leke horizons is a very conspicuous lumachelle bed of gryphaeas. Big nodules of flint occur sporadically in the marly chalk.

2. The upper part of the chalk series consists of more chalky limestone, locally termed Sultaneh. The top strata are extremly rich in irregularly shaped, yet bedded, flint concretions. A very thin limonitic bed in the non-flinty section was used as a conspicuous and constant marker.

3. In the uppermost part of the chalk series or above it, coarse dolomite occasionally seems to replace the flinty chalk. However, its exact stratigraphic position —whether belonging to the chalk series or to the "Upper Cenomanian" reef limestone series remained unsolved.

As for the southern Carmel; our knowledge depended originally on some fossils collected by Blanckenhorn near Ijzim and Zikhron Yaaqov which Boehm (1900) and he (1927) determined as Cenomanian and Turonian. It was evident, that the Turonian determination was influenced by the petrographic similarity of the lithographic limestones with the Turonian Mizzi helu containing in both cases *Nerinea* and *Acteonella.*

Particulary confusing became Blake's reference to Lower Cenomanian of the outcropping dolomitic rocks on the western Carmel at Zikhron Yaaqov and Wadi el Maghara (1936, handcoloured and printed map 1937, 1939); so more as the *Chondrodanta-Nerinea* reef limestone of Wadi el Maghara resembled lithologically the "Upper Cenomanian" reef limestone of Wadi Falah suggesting identical age.

Vroman (1938), who had dealt especially with the geology of the southern Carmel, put the dolomite of Wadi el Maghara on a par with the rocks "of the south end of the Carmel, north of Benyamina" (1938, p.3) which according to his geological map were transitory between Cenomanian and Turonian. Yet, on the other hand, in his facies section (Figure 1, p.7) these dolomites laterally replace there oldest outcropping "Cenomanian" rocks: Rudist limestone, Meleke and flinty limestone.

A contemporaneous age of the Zikhron and of the Wadi el Maghara-el Mazar dolomite with the Lower Cenomanian main dolomite complex of Yagur as suggested by Blake's map would furthermore demand a thickness in reduction of the Mid-Upper Cenomanian of several hundred metres, and this, within less than three kilometres distance.

It also became apparent that the "Middle Cenomanian" flint chalk series which appear underneath the Wadi Falah reef limestone were stratigraphically lower than Vroman's "flint limestone" of Zikhron and Ijzim.

In spite of all these notions, the stratigraphy of the Carmel was ascertained only as far as the lower and middle part of the Cenomanian: the main dolomite and the main chalk series was concerned. The upper part, the so-called "Upper Cenomanian", consisting likewise of dolomite, Meleke, flint chalk and flint limestone with

intermixed volcanics were still confused with the middle and even the lower part of the Cenomanian.

It was then the new field study of Kashai which especially clarified the socalled "Upper Cenomanian" stratigraphy as outlined in the following.

PRESENT STRATIGRAPHY (E. KASHAI)

1. Yagur dolomite or main dolomite complex
(ce_1 on 1956 geological and present map 1:100,000)

This formation as measured on outcrops has a thickness of 350 m, but may still be thicker. It forms the steep and pronounced cliffs on the Carmel slope above Yagur. While Picard originally termed it main dolomite complex, it is now also called Yagur dolomite. Whether one refers the main dolomite complex to the Lower Cenomanian or to the Vraconnian-Albian or to both stages is still a matter of research.

The lithological monotony of the rocks and their poverty of well preserved fossils makes a stratigraphic decision very difficult. Thus, our main attention was directed to the above-lying chalk series with its frequent change of lithology and its rich fossil content.

2. Main chalk complex
(ce_2 on 1956 geological and present map 1:100,000)

The chalky series forming the crowning hills of the Carmel on both sides of the crest between Haifa and Isfiya has the following subdivisions :

a. Lower or Isfiya chalk
b. Meleke-Gryphaea beds
c. Middle or Khureibe chalk
d. Upper or Juneidiya chalk ("Sultaneh" s. str.)
e. Volcanics in various interbeddings

a. Isfiya chalk. 70 m thickness. Slightly marly. White, but frequently yellowish due to limonitic concretions. Nodules of flint. Rich in fossils. Near Isfiya the chalk changes laterally into dolomite and crystalline limestone. A sporadic outcrop of breccious rudist reef limestone was observed.

b. Meleke-Gryphaea limestone beds. 10-20 m thickness. Hard coarse crystalline limestone, locally called Meleke, changes near Isfiya into a lithographic limestone, the top bed of which is completely composed of large gryphaeas. Both Meleke and gryphaea limestone form perfect markers.

c. Khureibe chalk. 120 m thickness. Similar to the lower chalk. Contains flint nodules and is rich in megafossils (including orbitolinas). Upper 30 metres consist of hard limestone and around Muhraqa of dolomite. Top bed highly limonitic, and again used as good marker.

d. Juneidiya chalk. 60-80 m thickness. Consists of chalky limestone called Sultaneh. Upper part rich in small and bedded flint concretions (between Khureibe and Damun). West of Muhraqa the flints appear in the lower part, and the upper part alternates with fine-bedded limestone. Juneidiya chalk is rich in pelecypoda and ammonites.

e. Volcanics. The stratigraphic position of the volcanics in the main chalk complex is described in a later chapter.

3. *Muhraqa and Daliya series*
(ce_3 on 1956 geological map 1:100,000)
(ce_3 t_1 on present map)

The stratigraphic unit following above is mainly exposed in the southern part of the eastern Carmel, i.e. in the neighbourhood of the convent of Muhraqa and of Daliyat el Karmil. After these localities two subdivision have been named: the Muhraqa limestone series and the above following Daliya marl-chalk series.

a. The Muhraqa series. 70-80 m thickness. Its lower part represents a crystalline reef limestone (Meleke) rich in rudists; its upper part is a detritic microorganogenic limestone with pseudo-oolithic micro-texture in the higher and well-bedded strata. The hard and reefy character of the Muhraqa limestone contrasts morphologically with the smooth land forms of the soft underlying Juneidiya as well as the overlying Daliya chalk. In several places, especially near the main border-fault of the eastern Carmel and near the exit of Wadi el Maghara, the Muhraqa limestone changes into dolomites. This phenomenon — as mentioned before — has caused much stratigraphic confusion, although their richness in *Nerinea, Acteonella* and rudists distinguish these dolomites from the rather monotonous looking rocks of most of the other dolomitic horizons.

b. The Daliya series. 60-80 m thickness. In the northern Carmel, this series somewhat resembles the softer beds of the main chalk complex, but is marly and poor in megafossils. Moreover, megascopic foraminifers such as orbitolinas are totally absent, but microfauna is present. Nodules of flint are rare and sporadic. Intercalations of thin lithographic limestone occur. Conspicuously dark grey chalk with a slight bituminous odour in a down sunken Cretaceous block south of Khirbet Jalameh is quarried by the Nesher Cement Company. In the southern Carmel, between Ain Ghazal and Fureidis, only the upper portion of the Daliya chalk series is exposed; a distinct change of facies has taken place. In lieu of typical Daliya chalk and marl we find flint and quartzolith-bearing yellowish marly dolomites with Meleke layers. (To the latter belong the 10 m thick Meleke of the Ytong quarry north of Fureidis.)

Some Meleke are rich in large silicified forms of *Pecten, Acteonella, Nerinea* and in small gryphaeas. The top of the Daliya series of this southern facies is well-marked by a yellow dolomitic marl, termed by us Fureidis marl.

4. *Umm ez Zinat and Shuna series*
(ce_4 on 1956 geological map 1:100,000)
(t_2 on present map)

a. Umm ez Zinat series. Above the chalk series in the North and the Fureidis marl in the South, there follows all along the southeastern flank of the Carmel from Umm ez Zinat to Zikhron Yaaqov a 50 m thick predominantly dolomitic series, termed Umm ez Zinat series. Again in the South around Zikhron Yaaqov this series may facially change and be then represented by well-bedded and flinty lithographic limestone. The top of the Umm ez Zinat series is everywhere distinguishable from the above-lying Shuna series by a light yellowish dolomitic marl, several metres thick, the Zikhron marl. The Zikhron marl is the most continuous marker in the Carmel and was observed from its southernmost promontory at the Benyamina quarry up to the easternmost corner, near Yoqneam. The Zikhron marl, rather rich in *Hemiaster, Pecten,* etc. at the type locality Zikhron Yaaqov, is remarkably poor in fauna around Umm ez Zinat.

b. The Shuna series. At Khirbet esh-Shuna, on the east flank of the southern nose of the Carmel, the rocks of this series are mostly a coarse Meleke of about 100 m thickness, with a middle part of 30 m thick dark, dense dolomite. This dolomite disappears, however, towards the North, between Qumbaza and Wadi Milh, the Shuna series consisting here only of coarse Meleke of detrital aspect.

5. *Qumbaza series*
(t_3 on present map)

Possibly the most uniform formation of the Carmel is the Qumbaza series. The lower part consists of a typical Mizzi helu lithographic limestone, 20-30 m thick, succeeded above by fine-grained crystalline limestone varying in thickness from 20 to 50 m. This series occurs all along the southeastern flank of the Carmel from Shuna to Yoqneam and from there in sporadic exposures (due to strong faulting) along the eastern border from Yoqneam to Jelameh.

Its constant dip towards the Megiddo-Ephraim synclinorium and the Qishon plain demonstrates the flank position of this formation.

6. *Senonian-Tertiary*

The Senonian and Tertiary formations outcropping mainly in the Ephraim synclinorial area and the block-faulted Qishon plain are not further discussed here.

7. *Volcanic intercalations*
(Cenomanian to Senonian)

90% of the volcanic material found in the Cretaceous are multi-coloured tuffs mainly of basaltic constitution. Genuine volcanic basic lavas occur only east of Mu-

hraqa and around Shefeya. Unaltered fossils, absence of proper disconformities and of terrestrial formations, interbedding in marine sediments — all point to submarine origin or deposition of the volcanics.

The main occurrences of volcanic rocks and their affiliation to the various stratigraphic marine horizons are given in the following list :

2 km north of Bat Shlomo	Senonian
Around Shefeya	Shuna series
Around Ofer	,, ,,
South of Ein Ghazal	,, ,,
1 km south of Ijzim	,, ,,
Around the valley of Maqura	,, ,,
East of Zikhron Yaaqov	Umm ez Zinat series
Umm et Tos (1km NE of Fureidis)	,, ,, ,, ,,
North of Ein Ghazal	,, ,, ,, ,,
Along the road E of Ijzim	,, ,, ,, ,,
1 km south of Ein Ghazal	Daliya series
The valley W of Ijzim	Daliya-Muhraqa series
The Valley E of Umm ez Zinat	Daliya-Muhraqa series
W and E of Muhraqa	Khureibe-Juneidiya series
Wadi Zarra'a (1 km S of Damun)	Isfiya series

SUMMARY ON LITHOSTRATIGRAPHY (E. KASHAI AND L. PICARD)

In the foregoing chapters the authors dealt with the stratigraphic sequences of the Cenomanian of the Carmel. A five-fold division was obtained. This represented in the sheet Zikhron Yaaqov (1:100,000) published 1956.
as :

ce_1 Main dolomite complex — Lower part of Cenomanian (to Albian), 350 m exposed

ce_2 Main chalk complex — Middle part of Cenomanian, 250 m

ce_3 Muhraqa-Daliya series Middle to Upper parts of Cenomanian, 150 m

ce_4 Umm ez Zinat-Shuna series Upper part of Cenomanian, 150 m

t Qumbaza series-Turonian

Volcanics were met with above the main dolomite in all the Cenomanian-Turonian horizons as well as in the Senonian. They are interbedded in or are facially replacing these marine formations.

PALEONTOLOGICAL REVISION OF LITHOSTRATIGRAPHY (E. KASHAI)

The very recent working up of the paleontological material by the junior author (E. K.) has brought a fundamental change in the age interpretations of this five fold division, to be discussed in his Ph. D. thesis.

Accordingly,

ce_1 remains the main dolomite complex or Lower Cenomanian

ce_2 remains the main chalk complex of Mid-Upper Cenomanian

ce_3 the Muhraqa-Daliya series is for its main part determined by Turonian fossils, especially as far as the Daliya series is concerned. The Cenomanian or Turonian age of the Muhraqa series is still under discussion. We propose, therefore, to regard:

ce_3 Upper Cenomanian of the 1956 map, representing the Muhraqa-Daliya series, as Cenomanian-Turonian transition series.* In the attached geological map the Muhraqa-Daliya series has therefore been indicated as ce_3 t_1.

ce_4 Becomes in our attached map t_2 and belongs to the Turonian.

t The Qumbaza series representing solely Turonian on the 1956 map can now be referred as t_3 to the upper section of the Turonian.

In view of this new stratigraphic division — the Cenomanian attains about 600 to 700 metres thickness and the Turonian the unexpected high figure of 200 to 300 m.

TECTONICS (L. PICARD and E. KASHAI)
(see Figures 1 and 3)

In Blanckenhorn's *Geologische Ubersichtskarte* (1912), most of the Carmel is bordered by one fault. Blanckenhorn apparently had a block structure in mind and in this he is followed by Fohs 1927, Figure 3). Blake's concept in 1928 (p. 26) was that of a "main arch embracing Carmel-Umm el Fahm and the Carmel-Safed anticline", in other words , a huge vault uniting Galilee and Carmel. Later (1940) he speaks also of the Carmel "block". Picard described this mountain in 1928 as "an independent and enormous upheaval which lifted the Carmel 1000 m higher than the Shefa 'Amr ranges". His section of Yagur indicates an anticlinal bending caused either by a flexure (1926) or by dragging of a fault towards the "Graben mould" of the Haifa plain (1931). Bailey Willis (1928) called the Carmel a "surface form swell" with "uparching due to ramp thrust" or "overthrust".

In Avnimelech's analysis (1936), faults, especially his strongly N-S directed western border fault, are emphasized, but the main structural accent is put on two anticlines: one, bordering as a straight NE line (Figure 13) the northwest flank of the Megiddo syncline (from Shefeya to Yoqneam approximately) and the

* The possibility of a Turonian age assignment to Kashai's Muhraqa limestone syn. with Picard's Rudist-Nerinea marble (1938, 1940) and Blake's Rudist-Meleke (1936) would eliminate the hitherto used tri-division of the Cenomanian and leave us instead: Lower Cenomanian or Main dolomite complex and Upper Cenomanian or Main chalk complex. This would raise again the age question of the Mizzi Yahudi-Ahmar horizon of the Judean highland. The faunal determinations of rather badly preserved specimens deriving from the dolomitic rocks were never too satisfying. At any rate, the finding of *Neolobites peroni* Hyatt from the Deryasini beds following immediatelly below the Mizzi Yahudi (Picard 1948) indicates a distinct uppermost Cenomanian age for the Deryasini.

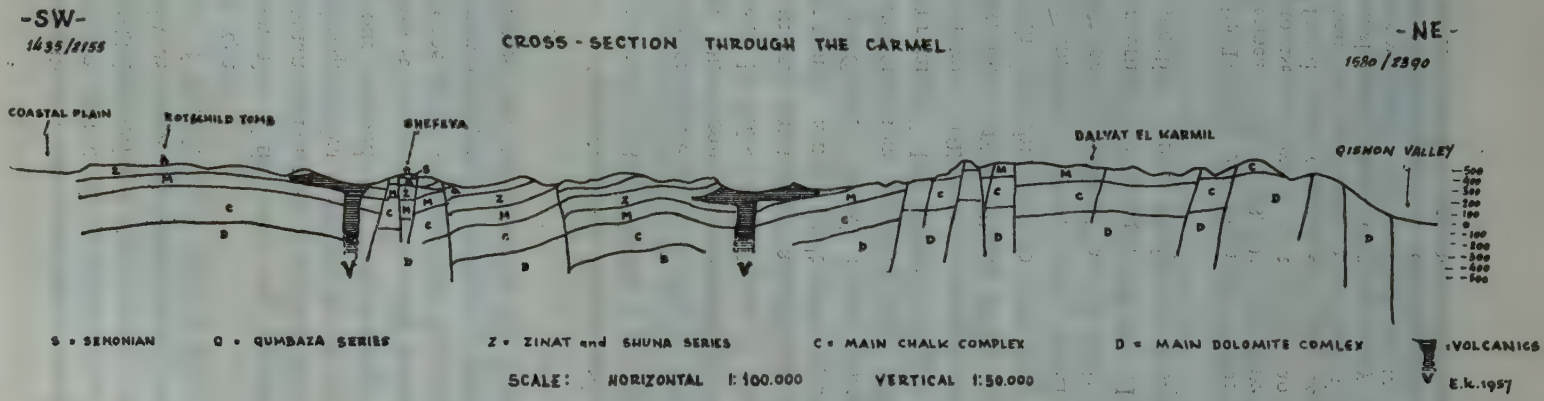

Figure 3.

Geological cross-section through the Carmel by E. Kashai. Scale horizontal 1 : 100,000, vertical 1 : 50,000.

other, transversally cutting the Carmel nose of Haifa (from et Tira to Haifa-town approximately).

Vroman's (1938) sections cross only the southwestern-most promontory of the Carmel. They indicate very shallow undulations, slightly disturbed by faults of minor displacements. Though Vroman (1938, pp. 44-47) mentions a "most probably" western borderfault near Zikhron Yaaqov, he also discusses the possibility of "coast erosion" and "wave-cut cliff" originating the western escarpment.

Picard distinguishes (1940, pp. 10-14, Figure 4) two anticlines in the northern Carmel: the small but well-developed Shellale anticline and the large Isfiya (Juneidiyat) anticline, separated by the Damun syncline. Later (Picard 1943, pp. 16, 17, 24), a more synthetic conception of the Carmel structure is outlined and given here in the following quotations:

A "typical upwarp with asymmetric (monoclinal) dip to NE and E" displays the large "anticline of Isfiya" having a "curving strike across the heights of Haifa, Isfiya, Muhraqa, Umm ez Zinat to Zikhron Yaacov, with structural crest in the Umm ez Zinat-Isfiya district. Transverse fractures at Yagur, Umm ez Zinat and Shefeya caused blockfaulting" on this "Isfiya-Umm ez Zinat-Zikhron Yaaqov fold range". "A second, smaller saddle zone, the Wadi Shellale anticline, stretches across Ijzim and Wadi Shellale" — "ends south of Tira" — and is transversed by many faults". "Between the two anticlinal zones there lies the synclinal zone of Damun extending in the North towards et Tira and in the SE to Daliyat el-Karmil".

"The depression of Ijzim" was regarded as a "fracture basin" due to N-S faults which border the eastern and western flanks of the depression. Major border faults in "the Northeast and particularly in the West" brought "downfaulting of the coastal region"; "part of the arch lies masked under the Mediterranean Sea".

In 1953, Ball speaks of the Carmel "horst" with "dip towards the Wadi Ara syncline without interruption by faulting".

In a short note, Picard (1954, p. 303) desbribed the Carmel again as a fault-bordered uplift with anticlinal pattern, but adds that the "folding and warping elements are not yet analyzed in a satisfactory manner".

The picture recently drawn by Bentor and Vroman (1954) is related to that given by Picard (1943). The differences lie in the straight outline of the Zikhron Yaaqov anticline and its tentative end near Ijzim, the termination of the Isfiya anticline at Umm ez Zinat and no reference to the Shellale anticline.

Apart from the solution of the crucial stratigraphic problems, the main aim of our work in the last two years on the Carmel, in connection with petroleum research for the Israel Continental Oil Co. was principally to find final evidence of the Isfiya anticline and its continuation toward the southern Carmel, the morphotectonic explanation for the intermountain Ijzim depression and the pros and

cons for a western border fault. For this purpose, some field trips were also extended to the northwestern Carmel.

Proper mapping of the structures of the NW Carmel such as the Hadar-Neve Sha'anan and Shellale anticlines, the 'Ein Hod and Daliya-Damun synclines, the major Haifa fault and many minor faults has been recently carried out by Karcz.*

In the attached structural sketch-map, the principal tectonic features are indicated and analyzed in the following:

1. *The Low Carmel anticlinal range or Zikhron anticline*

The axis of this anticline starts from south of Zikhron Yaaqov to Fureidis and branches off between Ofer and Ijzim (Kerem Maharal). The western branch crosses Wadi el Maghara and enters near el-Mazar into the coastal plain. The other shorter eastern branch dips in an undulatory manner into the Ijzim synclinal basin ascending from the depression again towards the heights west of Umm ez Zinat as High Carmel anticline. Like the latter, the eastern flank of the Zikhron anticline has a SE to E asymmetry. The western flanks are hidden below the Carmel coastal plain and the shelf region of the Mediterranean Sea. Shallow holes drilled in the Kabarra and Athlit plains disproved the existence of any major fault dissecting the southern Carmel from the coastal plain.

Seismic measurements assume a fault of larger displacement separating the Carmel southern promontory from a subsurface "High" around Caesarea. But this feature could also be explained by a flexure of the plunging Carmel nose. The only fault of morphological importance in the southern or Low Carmel is the N-S running fault bordering the Ijzim depression on the West. It apparently also has an influence on the origin of the depression east of Shefeya. The Ijzim West border fault, with about 100 m throw, turns near el Mazar in a NW direction and enters the coastal plain; in the South, it dies out in the Ephraim Eocene syncline.

The minor faults have an average throw of 30 m; they cross the Low Carmel anticline range in a curved and diagonal, mostly NW-SE direction. Only in the Ijzim part, do they adhere to a N-S direction producing minor graben-horst structures.

2. *The High Carmel anticlinal range* (*Former Umm ez Zinat-Isfiya anticline*)

Starting from the synclinal core of Ijzim (with Top-Turonian situated in the very interior of the Carmel), two small anticlinal branches soon unite (between Umm ed Daraj and Qumbaza) and rise as one anticline, first in a NE and then in a N direction towards Isfiya. The axis runs halfway between Muhraqa and Daliyat el Karmil, exposing main chalk series. Faults, of smaller and larger displacements, cut this axis transverally from a N-S direction in the South, to NW-SE and

* The results form a M. Sc. Thesis of the Hebrew University and will be treated separately.

finally NW-ESE in the North, demonstrating therewith their adjustment to the curvatury and contemporanity of development with the major anticline.

This anticlinal range, tentatively called Zinat-Muhraqa anticline (though both localities lie on the anticlinal flank), is dissected by a major fault of 250-500 m throw near and south of Isfiya.

The Isfiya mayor fault cuts right through the Carmel, first in an E-W direction and then, with a NW bend, to Wadi Shellale, entering the western coastal plain south of at Tira. The Isfiya-Shellale fault and the Ijzim (East border) fault produce thus a major fault-block transversed by the important road of the "Central" Carmel: 'Ein Hod-Daliyat el Karmil-Umm ez Zinat and Muhraqa.

The Zinat-Muhraqa anticlinal axis continues in a NW direction through the heights above Yagur exposing here as oldest rocks, the (Lower Cenomanian) main dolomite complex. This is the Isfiya anticline sensu stricto, although the axis lies again, not at Isfiya proper but between this village and Yagur.

The anticlinal axis of Zinat-Muhraqa is slightly horizontally displaced against the Isfiya anticline axis along the major Isfiya fault. The Isfiya fault is thus younger than the folding or, if contemporaneous, became rejuvenated after the folding. As it joins opposite Alroy* the Qishon major borderfault (between Yagur and Yoqneam), the Isfiya fault is most likely of Quaternary age.

The Yagur main borderfault has a throw of more than 1000 m at Nesher, placing Eocene next to Lower Cenomanian. From here, it turns to the West and enters the Carmel as a crescentic transversal fault — our former Tabil fault. Yagur-, Isfiya- and Tabil fault frame the most elevated block of the Carmel, termed Isfiya-Yagur block.

The Tabil crescentic, transversal fault also forms the southern boundary of the adjoining northwesternmost block of the Carmel, the Haifa block.

The axis of the Isfiya anticline is slightly shifted as a consequence of the Tabil fault and of a second transverse fault near Tel Hanan (Beled-esh-Sheikh) on the Haifa block. This makes the exact prolongation of the Isfiya fold-axis difficult to determine. At Neve Sha'anan, however, the anticlinal feature and axis are well exposed.

The Neve Sha'anan axis extends in the North to the Hadar quarter of Haifa, as also indicated on our former cross-section (1940), and recently verified by Y. Karcz.

3. *Shellale anticline*

Half-way between Tira and Daliyat el Karmil, the Carmel displays another, however, smaller and shorter anticline, the Wadi Shellale anticline. In the SE, it plunges due west of Daliyat el Karmil, and in the NW, it seems to end before reaching the coastal plain.

* More exactly Khirbet Mansura.

4. *Damun-Daliya syncline*

Parallel with the High Carmel anticlinal range, there follows between this range and the Shellale anticline a synclinal region. The axis starts west of Ahuza, runs then in a SE direction to Damun-Daliyat el Carmel and bends from here to the SW, ending in the Ijzim depression. Our former Damun syncline is thus better termed Daliya syncline.

5. *'Ein Hod syncline*

The 'Ein Hod syncline, lies between the Lower Wadi Falah and Wadi el Maghara, i. e. between the Shellale and the western branch of the Low Carmel anticline. The exact course of the axis, which starts somewhere near 'Ein Hod and ends in the South in the Ijzim depression, has yet to be determined. The 'Ein Hod syncline belongs structurally to the Central Carmel block, caused by the major fault of Isfiya-Wadi Falah and the Ijzim main east borderfault.

6. *The Ijzim depression*

The Ijzim depression is originated by various factors. Firstly, it is the meeting place of all the principal synclines and downbent anticlines of the Carmel. Secondly, a major N-S fault and smaller adjustment faults of similar direction produce a (more one-sided) graben-like feature. Thirdly, the large distribution of volcanic tuff was easily subjected to differential erosion. Thus the composite effect of synclinal folding, downfaulting and easily erodable material led to the formation of this intermountain basin.

It is therefore, no coincidence that here, at Ijzim, uppermost Turonian is still cropping out in the most interior part of the Carmel in the morphologically so conspicious flatbedded table-mountain of "Shanna".

The smaller plains of the Upper Shellale Valley, east of Yaarot Hakarmel and of the valley between Zikhron and Shefeya, are primarily the results of Wadi-erosion in volcanic tuff.

7. *The main block-structures*

In the foregoing pages, we have already dealt with major and minor faults cutting the Carmel in four major blocks : The southern or Zikhron-Wadi el Maghara block, the Central or Muhraqa-'Ein Hod block and the two northern blocks of Isfiya and of Haifa.

The central block is depressed and, between lower Wadi Falah and Wadi el Maghara of graben character. The highest uplifted block is the Isfiya horst, eleva-

ted against the lower blocks: the Haifa block in the North and the Muhraqa-'Ein Hod block in the South.

8. *Main borderfault*

The most outstanding borderfault of the Carmel lies on its northeastern flank. It starts somewhere in the subsoil of the Haifa Harbour and is, for its main part, hidden in the Qishon Plain, between Haifa and Nesher. From Nesher to Yagur and from there to Mansura, the fault-line can be much better defined and followed up to Yoqneam into the Ephraim syncline, where it dies out, or is taken over by en echelon step-faults belonging to the boundary region of the Ephraim Mountains and the Jezreel Plain. Step-faults and step-blocks are also well-developed along the Carmel main borderfault, placing, for instance, uppermost Turonian on the northern foot of the Muhraqa mountain next to uppermost Cenomanian. It is here, at Nesher, that the throw of the main borderfault attains its maximum figure of 1000 m decreasing rapidly to the East, towards Mansura-Yoqneam. Consequently, the Turonian blocks between Jelameh and Mansura contact with the Cenomanian or the Senonian blocks contact with the Eocene with relatively small displacement. The anticlinal flanks of the southern Carmel between Zikhron Yaaqov and Umm ez Zinat pass into the Megiddo-Ephraim syncline without any noticeable bordering strike-faults. Equally, we have to deny the existence of the assumed NS running borderfault, thought to separate the western Carmel from the western coastal plain. We arrive at the conclusion that the western cliffs of the Carmel are due to Pleistocene marine erosion followed in the South by talus accumulation. All the faults of some importance which cut the cliffs are a transversal feature of the Carmel, or diagonally cross the sub-surface of the plain as described in the following paragraph. Any major western fault, if present at all, must be hidden in the Mediterranean Sea.

9. *Main transverse faults*

These transverse faults were already discussed and termed: Shefeya-Wadi Maghara fault, Isfiya-Shellale fault and Nesher-Wadi Tabil fault. They have an average throw of 200 m and more. They may have originated as adjustment fault to the folding in Tertiary times, but were rejuvenated in the Pleistocene. We consider as a fault of purely Pleistocene age the Wadi Tabil disturbance, which crescentically meets at Nesher the main border fault.

The transversal fault which crosses Wadi Milh, east of Umm ez Zinat, has a most striking throw of 300 m, placing Senonian next to Cenomanian. This throw, however, decreases quickly both in the Carmel and, in the Ephraim mountains and adapts itself to the system of minor or adjustment faults.

Other quickly dying-out transversal faults are noted in the Haifa block dissecting the northwestern Carmel nose.

10. *Adjustment minor faults*

They are generally of small throw with an average of 30 m. In the Low Carmel anticlinal range, they cross the anticlinal axis in a curved, often diagonal direction. In the High Carmel, they have a N-S direction; in the South, they turn more and more in the NW-SE and finally WNW-ESE direction demonstrating with this radial arrangement their dependence and adjustment to the curved bending of the highest upwarped anticlinal range of the Carmel.

11. *Retrospect*

The Carmel is a folded upwarp with one major anticlinal range of 50 kilometres length, and minor anticlinal saddles such as the Ijzim and Shellale anticlines.

The bulk of the major anticline forms the High Carmel from Haifa to the Ijzim Low and the Low Carmel from Ijzim to its southwestern nose near Zikhron.

These ranges plunge in the NW into the Haifa Bay and in the SW below the subsoil of Benyamina-Caesarea. Especially asymmetric in the High Carmel, the major Carmel anticline is of a tectonic style similar to the rest of the major fold-ranges of the country. The eastern asymmetry makes it related to the Galilean upwarp.

East-West sections through the Carmel with large and small folding waves illustrate well the anticlinorial culmination of the folds in the North and in the East.

Consequently, there follows a regional basin of 15 km width to the East and SE of the Carmel, the Ephraim-Shefa 'Amr synclinorial deep with minor fold-wrinkles (of domal character).

No borderfault exists, which separates the Ephraim part of the synclinorium. Nor is the western coastal plain separated from the Carmel by a borderfault. The only borderfault, the Qishon main fault, runs along the NW rim of the Carmel from Haifa towards Yoqneam parallel with the Qishon. Accompanying step- and en échelon blocks, so familiar in graben regions, allows us to ascribe the Qishon fault zone to the well-known "Erythrean" (Picard 1931) fault depression of Galilee. Characteristically enough, these border blocks are completely absent in the western coastal plain or in the fold-flanks between the Carmel and Ephraim Mountains.

The Carmel is therefore not a horst. With its single main borderfault in the NE, it may at best be referred to as a half-horst.

Radially arranged transversal faults cut the Carmel in large fault-blocks: the Haifa-, Isfiya-, Muhraqa-, 'Ein Hod, and the Zikhron-Maghara block.

The Carmel is, thus a structural link between the block-faulted Galilee and the folded upwarp pattern of central and southern Israel.

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POSTCRIPT

In his publication of 1928 (p. 51) the senior Author (L. P.) described a detritic forananiferous limestone lithologically "resembling" the Neogene outcrops in the Haifa bay, and which he found in 1925 on the northeastern slope of the Carmel below Isfiya at about 400 m above sea level.

The occurrence was again discussed in 1931 (p. 167) and then a Miocene age suggested. A present micro-examination by Z. Reiss (letter of 2.3.58) revealed a "doubtless" Miocene age with *Amphistegina lessoni* L. and *Ammonia beccarii* d'Orb. indicating herewith the post-Miocene uplift of the Carmel of several hundred metres. This conclusion is in complete accordance with our conception on the uplift movements of the southern upwards of the Hebron and Northern Negeb Mountains discussed in 1943.

GEOLOGICAL BACKGROUND ON PETROLEUM DRILLING IN ZIKHRON YAAQOV (S. CARMEL)*

L. Picard
Department of Geology,
The Hebrew University of Jerusalem

Framing the Arabian shield or land mass the Alpine-Anatolian orogenic belt approaches with its outpost folds Syria-Israel-Jordan-Sinai (Picard 1937). The NE-SW Palmyrenian chains near Damascus (Syria) continue arc-like (Krenkel 1924) to Palestine (Israel and Jordan), obtaining a NNE-SSW strike which in the Sinai turns into an E-W direction (Picard 1943). The south Syrian-Palestinian fold ranges are, in a certain sense, comparable to the Saharian Atlas bordering the African shield. The north Syrian steppe plateau might be compared with the Algerian High Plateaux. And the regions of more complex structure of Amanus and Cyprus, bordering the northeastern Mediterranean corner, show similarity to the more Alpine styled Riff Atlas (Figure 1).

Northern Galilee, and still more the Carmel, are then immediately placed in a *paleogeographic position* rather remote from the depositional influence of the Arabian continent, otherwise recognizable in the outcrops of the mountainous Negev and Wadi Araba (South Israel and Transjordan) by immense Paleo-Mesozoic sediments of continental red beds character forming the major bulk of the so-called Nubian sandstone series.

There is thus ample justification to assume that more than in any part of the country, Carmel and westernmost Galilee remained — for most of the Paleo-Mesozoic periods — under the constant influence of the Mediterranean section of the geosynclinal ocean (the Tethys) accumulating here the *thickest* marine pre-Tertiary sedimentary cover. The great thickness of marine Jurassic at Mt. Hermon (5,000 ft.) and exposed Upper Jurassic at the Lebanon (2,100 ft.), of Albian (600 ft.) in central Galilee, of exposed Cenomanian-Turonian in the Carmel itself (3,000 ft.), surpasses by far the figures known in southern Israel. This should also hold for the Triassic, and still more for marine Paleozoics which, in the outcropping Nubian Sandstones of the southern Araba and eastern Dead Sea, is represented only by thin intercalations of marine Cambro-Silurian (Picard 1953).

* This report was presented to the Israel Oil Continental Company and Pontiac Petroleum Ltd. prior to drilling which started on September 21st 1954. We are indebted to this company for permitting publication of the report. It appeared also in Hebrew in the P. Solomonica memorial number of the Bulletin of the Israel Exploration Society, 1956, *22* (3—4), 121—128.

Received June 20, 1957.

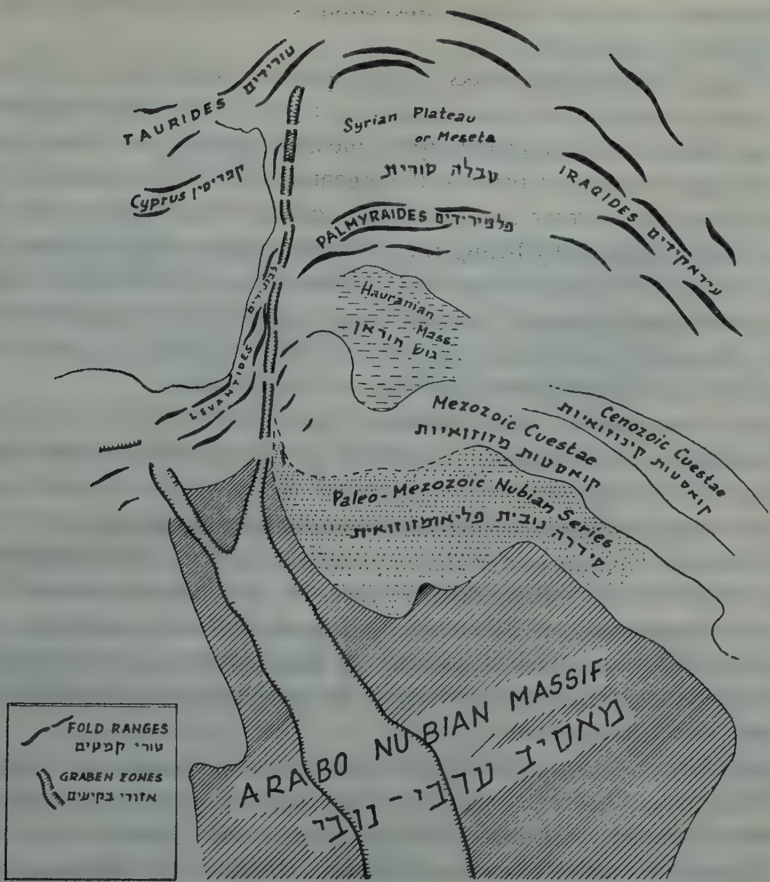

Figure 1

Morphotectonic units of the Middle East

Moreover, a considerable *change of facies from East to West* is observed all over the country. The difference is again best noticed on the Carmel, with its Upper-Middle Cenomanian chalk and flint laterally changing with volcanics — a picture which has much in common with island arcs of recent geo-synclinal seas or oceanic shelf slopes. Here, coral riffs have replaced the former rudist riffs.

Such facies changes are doubtless due to the irregular relief of the oceanic bottom and to vertical (block?) movements (Tromp 1949, Henson 1951) of the basement from early Paleozoic times. Yet, Cenomanian, and still more Turonian (the most widely distributed formation), is present in every district in the country. It is only after the overall transgressions of the Cenomanian-Turonian that district waves of bottom warpings can be recognized. They appear to have formed broad submarine swells — possibly a further effect of arching above "buried hills" basement, causing a thinning out of Senonian, and or Eocene strata towards the

top of the upwarps, or vice versa, a thickening towards the centre of the downbended submarine depressions.

The frequent sedimentary breaks in the Senonian and Eocene on submarine "Highs" and — only a few miles apart — a continuous sedimentation in the "Lows" as well as the non-metamorphic medium-consolidated character of the rocks speak against repeated periods of tangential stress of orogenic fold phases. It is more likely that further epeirogenic up and down movements took place in Senonian-Eocene times rarely lifting the submarine ridges above sea level. Indeed no unconformity of regional extension is visible but at best disconformities. The porper tangential push occurred between Lower and Mid Tertiary, between Oligocene and Miocene. It produced the present surface pattern of well preserved *anticlinal* and *synclinal folds* from the Negev to the Carmel.

The great accumulation in the synclines of up to 3000-4000 ft. thick Senonian-Eocene sediments, predominantly developed as non-pervious chalky rocks, has its fundamental bearings on the cover problem: it favours the synclines, and disfavours the larger anticlines of the mountainous area as far as the *post-Cretaceous* cover is concerned. In the case of the Carmel the retainer beds, therefore, start with the chalky and marly Cenomanian-Turonian, but must be more effective in the deeper horizons such as: Albian marls, Jurassic volcanics and shales, Triassic evaporites, etc. They separate beds of reservoir character such as: Lower Cretaceous and Lower Jurassic sands, karstic limestones and dolomites of Aptian, Mid-Upper Jurassic and Mid-Triassic, etc.

It is only in the Coastal plain that major anticlines plunge so deeply below surface that young Cenozoic formations may form an appropriate cover on the Cenomanian-Turonian axial strata. The situation is well illustrated on the cross-section (Figure 2) of the Caesarea subsurface structure, by the unconformable superposition of Neogene or Mio-Pliocene and Quaternary sediments. The sealing effect, however, is only partial as the Quaternary consists of continental porous sandstone, and the Neogene has over a thousand feet of fine grained shaley sand, or sandy shale with many coarser sand lenses of open gulf or inland sea character.

Faulting may have played a role in the layout of the Neogene inland bays and seas after replacing the pre-Miocene oceanic Tethys occasionally to become closed basins depositing important evaporites in many Near East and Mediterranean countries. Such pre- or early Miocene faults of regional magnitude are, however, difficult to define. Most faults of this age are adjustment faults of small displacements restricted to the anticlines, and dissecting them transversally or obliquely, without disturbing the general fold pattern (strike faults of larger extension as e. g. in the Raman region of the Negev are rare and may have continued to move up to the Pleistocene). On the other hand the Pleistocene is the most recognizable period of regional faulting deforming the country to the huge graben depressions of Jordan and Qishon valley or to the basin-ranges of Galilee which completely subdued the original pre-Miocene fold ornament (Picard 1954).

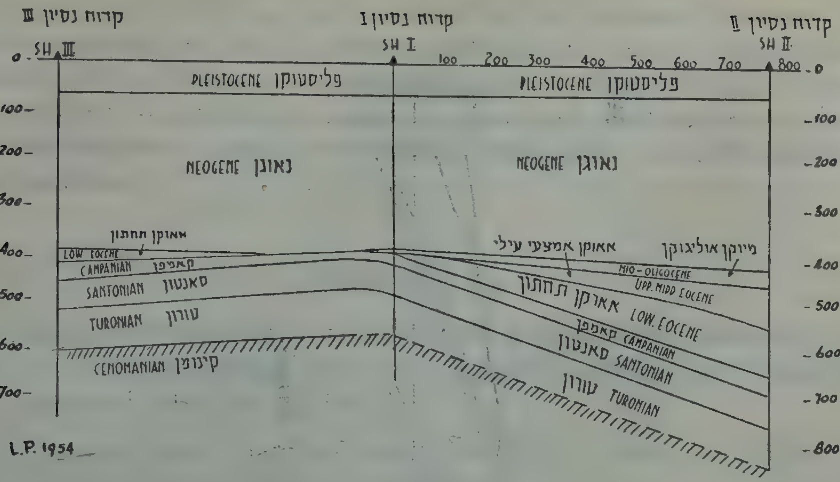

Figure 2
Cross-sections of structural drillings on Caesarea "High".

The Carmel is touched only on its northeastern border by the Pleistocene major faulting (originating the Haifa plain). From its northeastern to southwestern corner along a 25 kilometre axis the anticlinal structure remained intact with varying but stronger dipping to the eastern synclinorial basin (of Megiddo or Ephraim). Location Carmel No. 1 on Israel Continental Oil Co.'s licensed area Benyamina, was chosen on the southern half of the anticline, on the structurally highest point at Zikhron Yaaqov, forming here a subsidiary undulated dome of 180 feet local closure, the total closure amounting to several hundred feet. Drilling operation was carried out by Pontiac Petroleum Company, with a U 15 rig of 10,000 feet capacity. Drilling started on the Middle Cenomanian top* and was expected to meet the Lower Cretaceous basal strata at 4,000 ft., and the Jurassic base respectively Triassic top between 9,000 to 10,000 feet.

The Zikhron anticline is, however, only part of the anticlinal structure and consequently of the general uplift of the Carmel.**

Reasoning as to the nature of the steep western escarpment of the Zikhron Yaaqov Carmel — a fault scarp or a Plio-Pleistocene abrasion cliff led to the assumption that any major fault is absent on the western escarpment.*** A fault was, however, assumed separating the southwestern point of the Carmel anticline from its subsurface prolongation towards Caesarea. Such a subsurface feature had

* Most recently referred to the Turonian (see Picard and Kashai 1958).

** See geological map with structural features in Picard & Kashai (This journal, 1958, P. 3, fig. 1).

*** Structural drillings in connection with hydrological research of Mekoroth and the Israel Water Planning revealed indeed the continuation of the Cenomanian formation and Carmel structure below a thin cover of Pleistocene sediments and without any major disturbance. In Figure 3 we added these findings to Kashai's section.

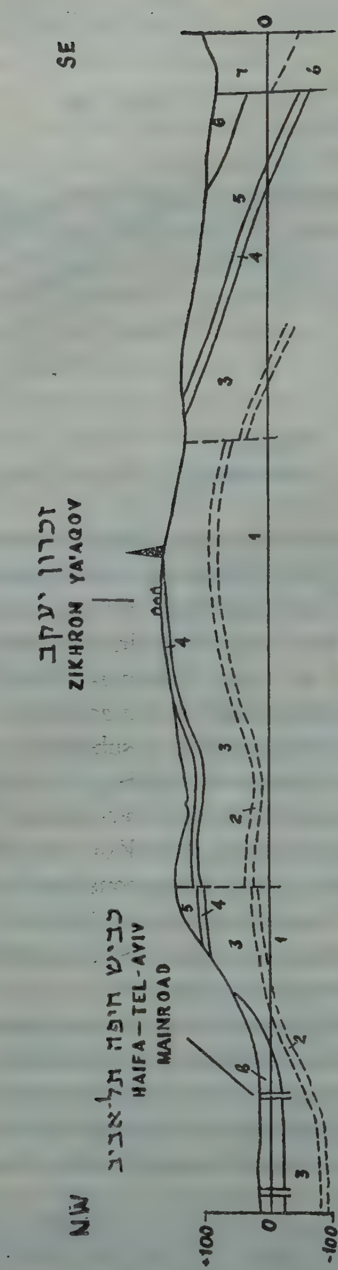

Figure 3

Geological cross-section of the southwestern Carmel (by E. Kashai)

1—5 Mid-Upper Cenomanian
6 Turonian
7 Senonian
8 Kurkar
9 Alluvium

been assured from former gravity surveys of the Iraq Petroleum Company's map further elaborated by seismic reflection shootings of the Weizmann Institute. Structural drillings of three slim holes (Figure 2) to depths of 1,800-2,000 ft. perpendicular to the strike and crossing a seismic high point confirm at least the typical SE asymmetry known in its northern prolongation on the SE slope of the Carmel anticline.

POSTSCRIPTUM

The drilling of Carmel No. 1 wildcat which terminated in February 1955, resulted in some confirmations and or revisions of our above-stated "reasonings" and "conclusions" which we add below:

(1) The Base Lower Cretaceous was found to be at 4,800 feet which is not too far from our rough prognosis of 4,500 feet.

(2) The Base Jurassic assumed at 9,000 feet must, however, be considerably deeper as the terminal layer of the Carmel well was still in the main Jurassic limestone-dolomite complex.

(3) Our conclusion: "The Carmel most likely contains the country's thickest and most contiinous marine sedimentary column" holds firm to an even disappointing degree. Thus for instance, the Lower Cretaceous shelf-sands so important as reservoir beds at Heletz (Huleiqat), not to speak of the continental Wealden sands of Syria-Lebanon and Negev were almost completely absent in the southern Carmel and instead represented by genuine marine calcareous beds.

(4) The postulated interstratified shales indeed appear quite frequently. A most characteristic black shale series of good cover quality and possible source bed character, considered by the writer as Portlandian-Lusitanian, has now been traced as a consistent marker horizon in most of Israel's recent wildcat deep-holes (Halutza, Beeri, Tel Safit, King David, Petah Tiqvah, Kurdaneh).

(5) The calcareous rocks of the Jurassic were indeed "partly porous, partly compact".

(6) Considerable dead asphalt was encountered in the Middle-Upper Jurassic calcareous and volcanic rocks; a phenomenon which should encourage further search for fluid hydrocarbons in Jurassic (pre-Portlandian) layers.

(7) Several hundred feet of unforeseen volcanic agglomerates were found in the Middle-Upper Jurassic.

(8) Recent research (Picard and Kashai 1957) ascertained the great anticlinal feature from Zikhron Yaaqov to Umm ez Zinat confirming our former view (1943) that this foldrange continues in the northwestern Carmel towards its highest structural (and topographical) elevation above Yagur.

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AN ARTESIAN AQUIFER OF THE SOUTHERN DEAD SEA BASIN

Z. L. Shiftan

The Geological Survey, Ministry of Development

A. INTRODUCTION

In 1951 the Geological Survey of Israel started an investigation of the possibilities of the development of groundwater resources in the area surrounding Sdom. This investigation was carried out by the author in close cooperation with L. Picard. As a first result, it was recommended to drill into the Cretaceous limestones and dolomites at the base of the cliff limiting the Dead Sea basin in the West, and four prospective sites were indicated. At the same time, the Hydrological Service of the Ministry of Agriculture carried out a survey of the springs in the Sdom region. During 1953/54, a series of surface resistivity measurements were carried out by A. and E. Loehnberg, Consulting Geophysicists, in order to investigate the extent in depth of recent gravel deposits and to appraise the possibilities of exploitation of groundwater by shallow wells. In 1955, the Research Department of Water Planning for Israel Inc. carried out a survey of the Nahal Zin in order to investigate possibilities for flood control.

Following Picard's and Shiftan's recommendations, drilling was started by Water Planning for Israel Inc., on the site of Ma'avar Sdom (Naqeb el Mezzel), on the new Sdom-Beersheba highway. Operations, however, were soon suspended because of technical difficulties arising from an occurrence of liquid asphalt in the hole. Later, Israel Oil Prospectors, Inc., brought down a well in the immediate vicinity of the abandoned water well, named Mazal No. 1, in which water under artesian pressure was struck. A structural hole and a series of seismic shot holes drilled by the same Company in the lower Nahal Zin also struck water under artesian pressure.

Water Planning for Israel Inc., drilled two wells in the lower Nahal Zin, with the aim of obtaining water from shallow gravel deposits, as recommended by Loehnberg. One of these wells was successful. Later, two more wells drilled in the vicinity were successful too, one of them being a flowing well.

In this paper, the geohydrological data hitherto available will be summarized, and an attempt is made to arrive at conclusions concerning the origin of the groundwater and the possibilities of its future exploitation.

B. ACKNOWLEDGEMENT

The writer is obliged to the Hydrological Service of the Ministry of Agriculture for permission to use and publish in this paper data collected by that Department. The chemical laboratory of the Mekoroth Water Company has kindly permitted the use and publication of the chemical analysis of a series of water samples. Lapi-

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doth and Israel Oil Prospectors Inc., have given the author free access to their data, and in various discussions with the geologists of this Company many interesting suggestions have been brought forward. Sh. Mandel, hydrologist, Water Planning for Israel, has kindly calculated the figures for transmissivity and storativity for the pumping test of the well Nahal Zin No 3. The Jordan Exploration Company kindly permitted the use of many surface and subsurface data included in an unpublished oil prospection report by Picard and Vroman (1946).

C. CLIMATE

The climate of the Sdom area is, like that of the rest of the Dead Sea region, hot and dry. The 15-year average of yearly rainfall is 57.2 mm at Sdom, this quantity being distributed over an average of 11 rainy days/year.

Rainfall over the highlands in the West is between 100-200 mm/year and over the mountains of Moab in the East as high as 400 mm.

The monthly means of temperature vary between 16° C for January and 33° C for July. The mean relative humidity is 59% in January and 48% in July. The total annual evaporation is estimated at 2200 mm.

D. PHYSIOGRAPHY AND GEOLOGICAL STRUCTURE

The Dead Sea Basin is a part of the well-known Syrian-African rift. It is an elongated graben, directed approximately North-South, passing in the North into the

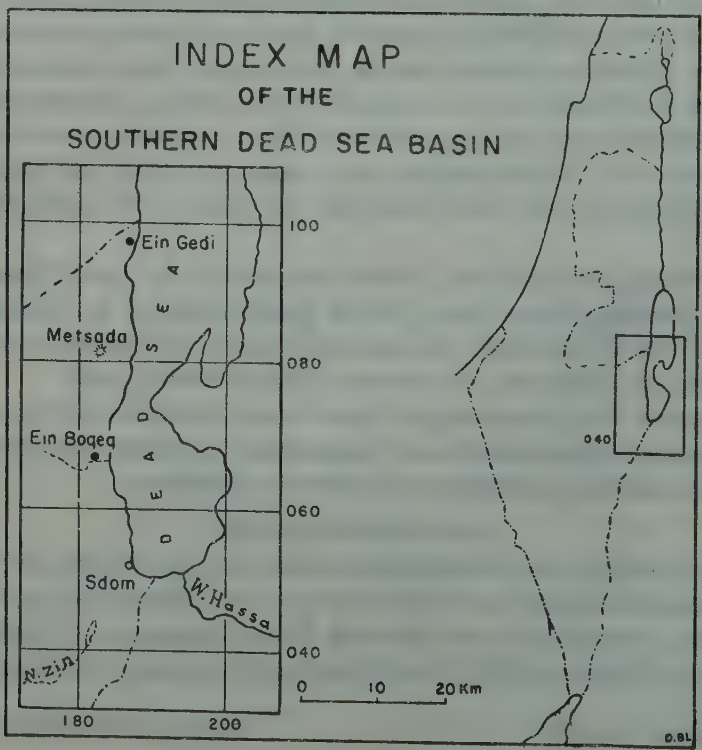


Figure 1

Jordan Valley and in the South into the Valley of the 'Arava (Wadi 'Araba). The Dead Sea itself is a lake without any outlet, approximately 80 km long and of a maximal width of 18 km. Sdom is situated on the southwestern shore of the Dead Sea (See sketch map, Figure 1). This paper deals with the stretch of the western Dead Sea shore from Nahal Boqeq in the North to Nahal Zin in the South.

Of the two uplifted block systems adjoining the Dead Sea graben in the East and the West, the eastern one, comprising the mountains of Moab, is relatively more elevated than the western one*. Rocks of Paleozoic and Proterozoic age are found at its base along the fault scarp. In the western block, the oldest rocks outcropping on the graben border are of Upper Cretaceous (Cenomanian, Turonian, Senonian) age. Outcrops of older rocks are to be found only in the northern and central Negev highlands, farther West and Southwest, in the cores of eroded anticlines such as Makhtesh Gadol (Kurnub), Makhtesh Hadira, Nahal Marqab and Nahal Yarqam. These are of Lower Cretaceous and even Jurassic age. The "Nubian Sandstone" facies is characteristic for these rocks as well as for most of the Paleozoic of Moab (Transjordan).

Whereas the highlands of Moab are of a rather flat geological structure, the mountains of the Judean (Israel) side of the graben are distinctly folded into a series of anticlines and synclines. Close to the mountain border, on both sides of the graben, faults are a predominant feature, but are of minor importance in the Judean and northern Negev Highlands. Some of the faults forming the complex graben structure may be hidden from surface observation by the cover of young sediments. The difference in relative elevation between the two blocks framing the graben makes itself apparent not only geologically but also physiographically. The plateau of Moab shows an average elevation of 1000 m above Mediterranean Sea level, whereas the mountains on the west side of the Dead Sea Basin hardly reach the height of 700 m M.S.L. with their highest peaks.

In the mountains of Moab originates the single perennial stream abutting into the Dead Sea from the South, the Wadi Hesa. The major drainage artery reaching the Sdom area from the Western highlands is the Nahal Zin (Wadi Fuqra), an intermittent stream flooded almost every year as a result of storms breaking over the Northern Negev.

The graben itself representing the lowest elevation on the surface of the globe (—392 m) was formed originally during the Miocene** but was established in its present outline during the early Pleistocene. It has been filled up by tremendous amounts of continental sediments of terrestric, brackish and lacustric facies, ranging in age from Neogene (or earlier) (Usdum Series) to Pleistocene (Lisan Series. — These sediments include shales, clays, sandstones, coarse clastics and also evaporites such as rock-salt and gypsum. The Middle Pleistocene Lisan Series is of special importance in connection with the groundwater resources of the Sdom region. It consists of a series of finely laminated clays, marls, soft chalk and gyp-

* For the understanding of the regional geological position of this area consult also Picard's cross-section from the Mediterranean to Moab (1953).

** Bentor and Vroman suppose an earlier origin.

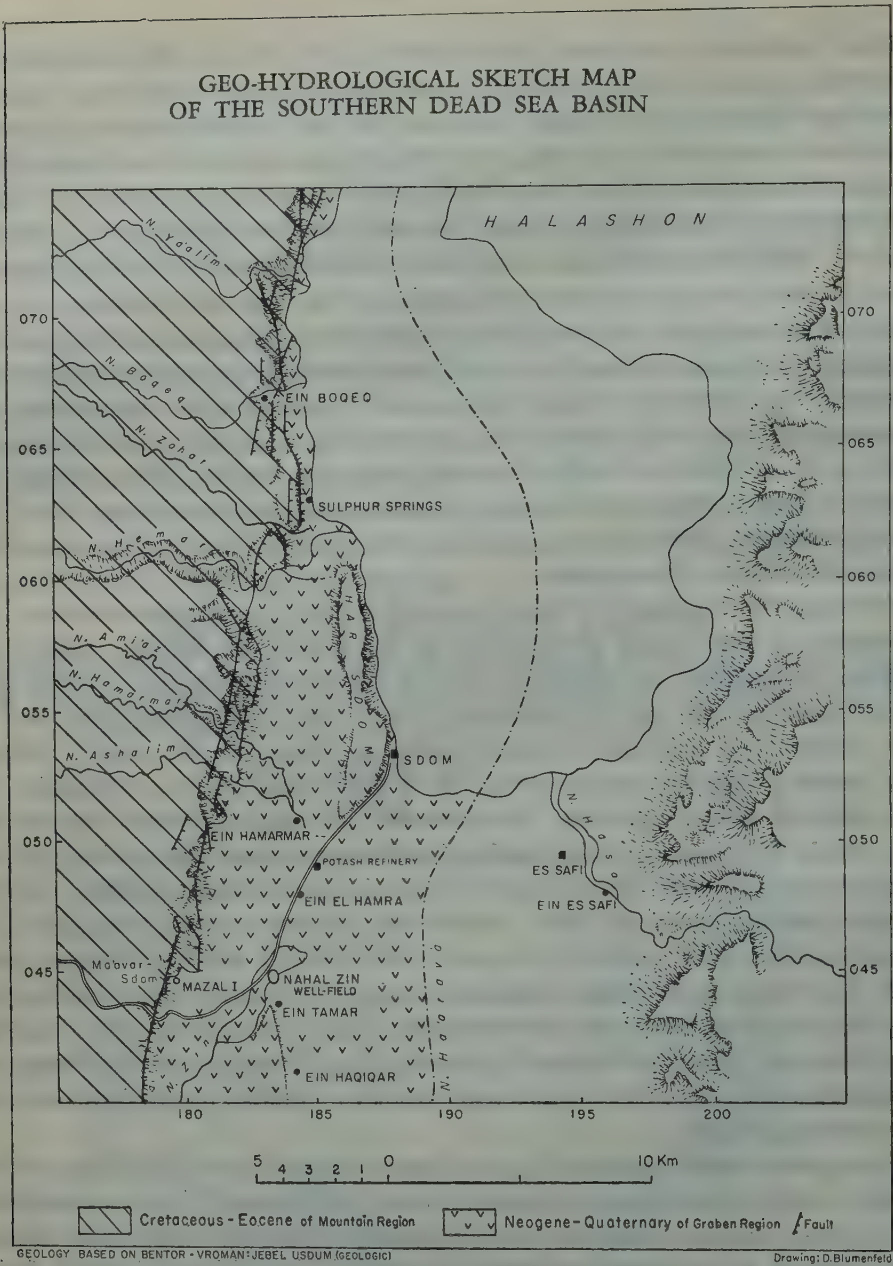


FIGURE 2

sum beds, interbedded with sands and gravels, especially in the lower portion*. The sand and gravel beds of the lower part of the Lisan series constitute the main

* "Travertine" mentioned by Picard elsewhere as underlying the Lisan series ("Samra") was also found covering the mesa-hilltops of the Lisan beds in the Lower Nahal Zin region.

aquifer of the Sdom area, while the overlying clays and marls act as confining stratum.

The pervious beds, being old alluvial fans, lake and river deposits, are not necessarily continuous but may wedge out both laterally and towards the centre of the basin.

Young tectonic movements have affected these Neogene-Quaternary sediments and resulted in the formation of the salt mountain of Sdom (Har Sdom), built up of rock-salt, gypsum, shales, clay and sandstones (probably of Miocene age), rising abruptly with its steep cliffs out of the Dead Sea on its southwestern shore.

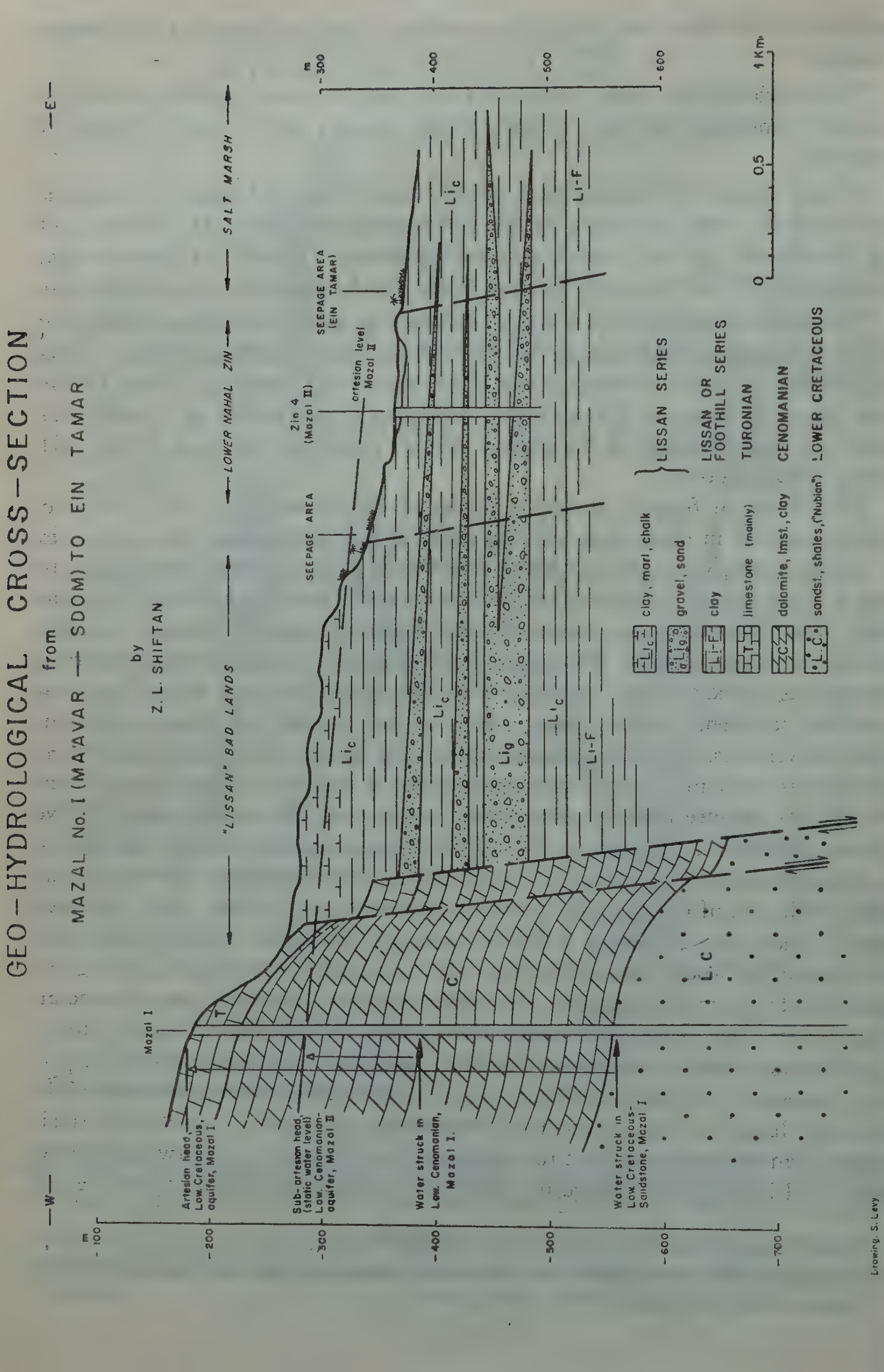
The maximal thickness of the graben filling as well as the throw of the main faults is unknown. Test-holes drilled in the Sdom area, near Mount Sdom, reached at a depth of 700 m neither the mountain formations (Cretaceous, or even Eocene) nor the early Neogene Usdum beds. According to the results of a gravity survey* the total thickness of the graben filling varies, in the central part, between 2000 to 7000 m.

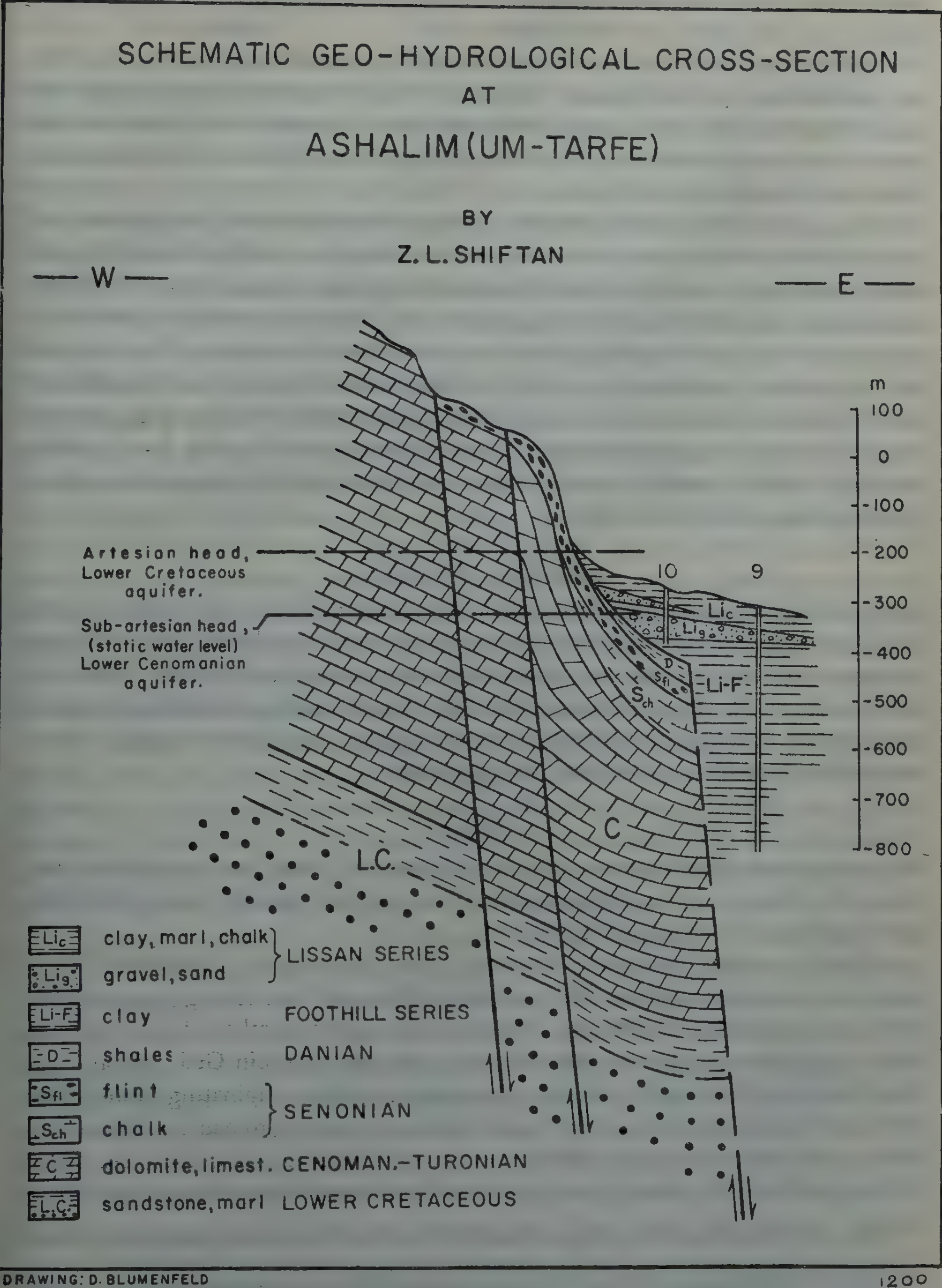
The structural features along the border of the mountains in the West are of special interest in connection with the study of the underground water resources.

In the South, from Ma'avar Sdom southwards, a single border fault appears on the geological map. From Ma'avar Sdom northwards, as far as Metzada, the mountain border is built up by a series of fault blocks, arranged in general according to the step-fault pattern, interrupted occasionally by a horst structure occurring among the blocks**. The continuation of this type of structure below the young covering sediments of the graben, which, at least in part, are younger than the fault movements, has been proved by bore holes in the Nahal Amaz area, where Cretaceous (Senonian) rocks were encountered at relatively shallow depth at one to 1½ km distance from the easternmost visible fault line on the main cliff. No positive evidence is available so far for the assumption, that a single fault line or a relatively narrow belt of faults exposed on the mountain border also means that these faults are of considerable throw and confined to a narrow strip, although part of them may be hidden below the younger formations of the graben. Such an assumption would however explain the conditions facilitating the passage of groundwater from the mountain formations into the Lisan beds along the mountain border. This would occur only where faults of considerable throw cause a juxtaposition of the Cenomanian-Turonian aquifer of the mountains and the pervious layers of the graben sediments (e. g. from Ma'avar Sdom southwards). On the other hand, in areas where a series of blocks separated by faults with small throw form the transition from the highlands to the basin, (e. g. between Ma'avar Sdom and Boqeq), the passage of water from the mountain aquifer into the po-

* Carried out by Nettleton for the Jordan Exploration Co.

** Defined by Fehr (verb. comm.) as "piano key structure"; these are Picard's "step-like blocks framed by curved faults" (1931, p. 22).


GEO-HYDROLOGICAL CROSS-SECTION
from
MAZAL No. I (MA'AVAR — SDOM) TO EIN TAMAR
by
Z. L. SHIFTAN
—W—
—E—
"LISSAN" BAD LANDS
LOWER NAHAL ZIN
SALT MARSH
SEEPAGE AREA
Zin 4 (Mazal II)
artesian level Mazal II
SEEPAGE AREA (EIN TAMAR)
Mazal I
Artesian head, Low. Cretaceous, aquifer, Mazal I
Sub-artesian head (static water level) Low. Cenomanian-aquifer, Mazal II
Water struck in Low. Cenomanian, Mazal I.
Water struck in Low Cretaceous-Sandstone, Mazal I
T
C
L.C.
Li c
Li g
Li-F
m
-100
-200
-300
-400
-500
-600
-700
clay, marl, chalk
gravel, sand
clay
limestone (mainly)
dolomite, lmst., clay
sandst., shales, ("Nubian")
LISSAN SERIES
LISSAN OR FOOTHILL SERIES
TURONIAN
CENOMANIAN
LOWER CRETACEOUS
0
0.5
1 Km
Drawing: S. Levy



SCHEMATIC GEO-HYDROLOGICAL CROSS-SECTION
AT
ASHALIM (UM-TARFE)
BY
Z. L. SHIFTAN
W
E
m
100
0
-100
-200
-300
-400
-500
-600
-700
-800
Artesian head, Lower Cretaceous aquifer.
Sub-artesian head, (static water level) Lower Cenomanian aquifer.
10
9
Lic
Lig
Li-F
D
Sfl
Sch
C
L.C.
Lic clay, marl, chalk
Lig gravel, sand
LISSAN SERIES
Li-F clay FOOTHILL SERIES
D shales DANIAN
Sfl flint
Sch chalk
SENONIAN
C dolomite, limest. CENOMAN.-TURONIAN
L.C. sandstone, marl LOWER CRETACEOUS
DRAWING: D. BLUMENFELD
1200

FIGURE 4

rous beds of the graben could be easily blocked by impervious beds of Senonian-Eocene (and younger) age (see Figure 3, 4) *.

In other cases, the thickness of the Lisan beds is reduced near the mountain border, and the top of the Neogene "Foothill" beds of a predominantly shaly and clayey character, with some intercalated sandstones, is found at relatively shallow depth. These beds would then block the passage of groundwater from the mountains into the subsoil of the basin.

Although the details of the subsurface geological structure along the graben border near Ma'avar Sdom and from this point southwards are still unknown, structural and stratigraphic conditions may facilitate the passage of groundwater from Cretaceous (and older?) rocks of the mountains in the West into sand and gravel beds, interbedded with and covered by clays and marls of the Lisan Series. Hydrological and geochemical considerations, to be described in detail below, provide sufficient proof for this explanation of the origin of the groundwater of Sdom. This groundwater is already of a confined nature at the border of the rift valley — as proved by wells — and remains confined farther east because of the impervious nature of certain layers of the Lisan Series.

E. SPRINGS AND WELLS

In spite of its extreme aridity, the Sdom area is comparatively rich in springs and water seepages. A considerable number of holes have been drilled, most of them in connection with oil and oil-shale prospecting, including a seismic survey. A small number only were drilled as water wells. The existence of an artesian aquifer in the subsoil of Sdom was discovered while drilling a large-diameter and a structural hole as part of an oil-prospection programme.

1. *Springs*

The springs and water seepages of the southwestern Dead Sea area arise in part from the Cretaceous rocks of the mountain area, in part from the young (late Tertiary-Quarternary) deposits of the basin.

a. *Springs arising from the Cretaceous of the mountains* (*Cenomanian-Turonian*). In the area covered by the present survey, only one spring occurs in the mountain formations, 'Ein Boqeq ('Ein Um Baghaq). A number of other springs of this type, however, occur farther north, in the Metzada-'Ein Gedi region, e. g. 'Ein Eshed and 'Ein Gedi. All these are contact springs originating from layers above the Cenomanian clay-marl beds (K-2 of Bentor-Vroman's designation). Their yields and other characteristics, as far as records are available, are listed in the appendix. The karstic character of the limestone-dolomite beds of the Ceno-

* There are however, other structural conditions that may facilitate the passage of groundwater from the mountains into the depression, such as reduction of thickness of the impervious Senonian layers. Thus, a contact between the Cenomanian-Turonian aquifer and pervious Neogene-Quaternary beds may be established, as in the case of 'Ein Hazeva and 'Ein Yahav, where water under artesian pressure has been discovered recently.

manian and Turonian above the impervious beds certainly contributes to the character of these springs.

No conclusions as to the size of the catchment area of these springs can be arrived at by hydrological- statistical methods today, because of lack of sufficient observational data. There can be no doubt that these springs drain part of the shallow subsurface run-off of the terrains built up by the Turonian and Upper Cenomanian dolomites and limestones in the Southern Judean — Northern Negev highlands. The relative abundance of contact springs situated actually within the mountain area — although rather close to the border fault — between Nahal Boqeq and 'Ein Gedi, proves the existence of a perched aquifer in this region dissected probably into several separate catchment areas. The region north of 'Ein Gedi however, is characterized by the relative scarcity of such contact springs as well as by the relative abundance of springs of the "hot spring" type, arising along fault lines close to the Dead Sea shore*. Hot springs, on the other hand, are scarce between Sdom and 'Ein Gedi, and in the Sdom area only the Sulphur Springs on the Boqeq shore represent this type of springs. The lack of contact springs North of 'Ein Gedi may well indicate an integration of the subsurface run-off of the Turonian-Upper Cenomanian within the Lower Cenomanian (or even older beds like Lower Cretaceous), effected by contact of these two aquifers along faults. All this groundwater would percolate to considerable depth, and appear in the form of hot springs on the main fault ('Ein Gedi to 'Ein Feshkha). Such an integration, however, may take place south of 'Ein Gedi as well, by reabsorption of water from contact springs into the groud in areas built up by Lower Cenomanian rocks.

The absence of springs arising directly from the Cenomanian-Turonian rocks on the main cliff in the area between Sdom and Nahal Zohar shows that the underground drainage of these formations is effected in part by the Boqeq sulphur springs, but mainly by the extensive seepage areas and springs occurring in the graben area itself near Sdom. Geological as well as geochemical and hydrological considerations are strongly in favour of this explanation.

b. *Springs arising from the Tertiary-Quaternary Sediments of the Dead Sea Basin.* This second group of springs includes the springs and water seepages along the 'Ein Haqiqar — 'Ein Tamar line as well as the smaller springs and seepages between the mouth of the Nahal Zin near Km. 4 of the Sdom highway and the southern tip of Mt. Sdom (including 'Ein Heimar). The springs along the 'Ein Haqiqar-'Ein Tamar line originate apparently from the Lisan Series, rich in sand and gravel beds, especially in the outcrops along the southern part of that line. The line of springs coincides with the morphological cliff of the Lisan formation at the rim of the Ghor — the saline mud flat and salt marsh south of the Dead Sea — representing according to Black and Shaw a fault. Geophysical investigations on the

* Actually, no springs of the contact spring type appear on the maps between 'Ein Gedi and the Wadi el Qilt, above Jericho. A series of springs and seepages is known however, in the Lisan beds of Deir Hajla, North of the Dead Sea. Their water may also originate from the Cenomanian-Turonian of the highlands (discussed also by Picard (1931)).

northern continuation of this line beyond Nahal Zin provide additional evidence for this assumption. On air photographs, several SSW-NNE directed lines suggestive of faults are visible within the terrain of the Lisan Series between Nahal Zin and Mount Sdom. The cliff of the Lisan beds along the Sdom highway, showing a similar direction, may therefore represent a fault line too. (An alternative explanation for this line, as well as for the 'Ein Haqiqar-'Ein Tamar cliff would be an old lake cliff). The entire area is extremely rich in spots covered by dense vegetation, and small springs arise in almost every gully cutting through the Lisan badlands. Part of these springs are of considerable salinity, especially those close to the Potash Plant and Har Sedom ('Ein Hamra). The salt beds of the "Usdum Series" (Picard), outcropping on Mount Sdom, may exist here at comparatively shallow depth and the water of these springs, as well as that from seismic shot holes to be described below, may leach out these salts. Concentration by evaporation in the seepage area may also add to the salinity of the springs*.

It seems highly improbable that these extensive water seepages and springs are due to direct recharge of the groundwater by precipitation in the Sdom area itself. The yield of the two major springs, 'Ein Haqiqar and 'Ein Tamar, is fairly large (20-100m^3/hr). Aproximately 20-50 m^3/hr. are supplied through a lined canal from these springs to the Potash Plant. There is no well-based estimate for the total amount of water arising from the ground in the Sdom region, and lost by evapo-transpiration, but an order of magnitude of 10^6 m^3/annum, taking total evapo-transpiration as 2000 mm and area of vegetation and seepages as 5 km^2, would represent a cautious estimate. It would be hard to explain this estimate by the scant amount of rainfall in Sdom, or by recharge from occasional floods of the Nahal Zin alone. The possibility of passage of groundwater from the mountains into the Sdom basin has, therefore, to be considered as a possible explanation as well as recharge into Lisan and mountain formations by storm-water run-off from various intermittent streams, especially Nahal Zin.

The sulphur springs arising out of young conglomerates directly on the Dead Sea shore near Boqeq indicate by their high temperature their extremely high salinity and their radioactivity, a deep-seated origin connected with faults.

2. *Wells*

The geological and hydrological data for the bore holes drilled in the Sdom area are given in detail in the Appendix. Here, the data leading to conclusions as to the hydrogeological conditions will be discussed and interpreted. The shallow bore holes, with a depth not exceeding 150 m, and the deeper ones will be considered separately.

* The water of these springs is still much less saline than the Dead Sea and little fishes have been observed in the small streamlets running for some hundreds of metres downstream of the springs before their water evaporates in part and is readsorbed in part into the ground.

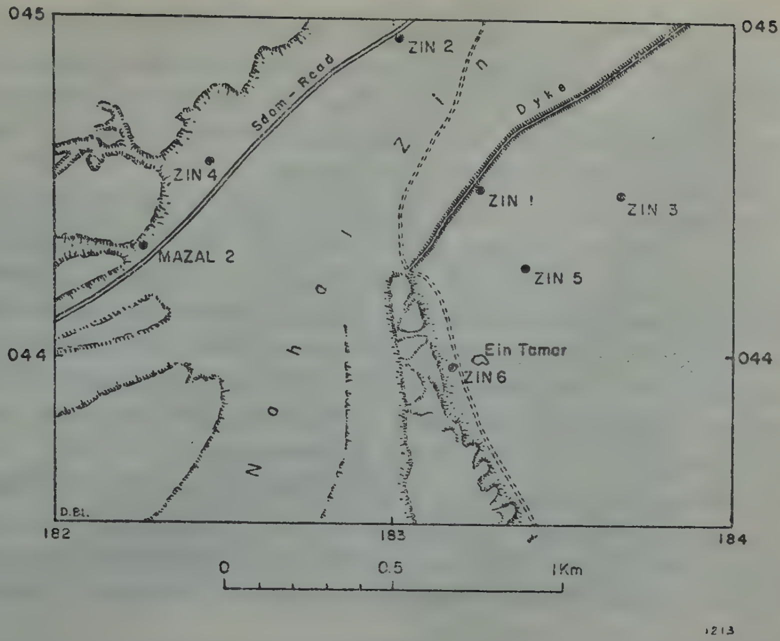


FIGURE 5
Location of springs and bore-holes in the lower Nahal Zin

a. *Shallow Bore Holes.* Four relatively shallow wells* were drilled by Water Planning for Israel Inc. (Tahal) and one by Israel Oil Prospectors in the Lower Nahal Zin (see Figure 5) at its exit from the Lisan badlands into the Sdom plain, near Km. 4 of the Sdom highway. The first three wells of Tahal (Nahal Zin Nos. 1, 2 and 3) were drilled with the aim to test the recent gravel beds of the Nahal Zin for possible subsurface storm-water run-off. Of these three, Nos. 1 and 3 were successful. Unfortunately, no detailed geological data are available for Zin Nos. 1 and 2. Both of the two successful wells (Nos. 1 and 3) are capable of yielding 50-75 m^3/hr. per 1 m draw-down. It was therefore taken for granted that the objective of the drilling programme was achieved, and the existence of shallow groundwater in the gravel beds of Nahal Zin, being a result of floods, had been proved.

There were, however, two facts that could hardly be explained by this conception; the high chlorine salinity of the water (900-1000 mg/1) and the results of the drawdown — recovery test carried out at Nahal Zin No. 3. This test revealed a high transmissivity of 4350 m^2/day combined with a low storativity of 0.7% thus suggesting the confined nature of the aquifer. The hydrological tests revealed, furthermore, a comparative large lateral extension of the aquifer.

A structural hole drilled by Israel Oil Prospectors Inc., known under the name Mazal No. 2, located in the same vicinity, struck water under artesian pressure

* A fifth well has been completed at the time of publication of this paper.

(2 atm. at surface) at slightly greater depth than the Tahal wells Zin 1 and 3. The pressure head (—330m) is about 60m lower than the head of the Cenomanian aquifer of Mazal No. 1, to be described below. This difference is easily explained by the extensive seepage and outflow in the area of the Lisan sediments, especially on the 'Ein Tamar — 'Ein Haqiqar line of springs.

After the discovery of the artesian aquifer of Sdom by well Mazal No. 2, another well was drilled by Tahal in the same area, with the intention to strike the same artesian aquifer. This well, Nahal Zin No. 4, brought forward the full geological and hydrological information that was, unfortunately, lost at Mazal No. 2. The surface gravels were dry here, and water was struck at a depth of 21 m and rose immediately to 17 m below the surface. Upon continuation of drilling, the water level rose continuously and finally the well started to flow. The strata consisted of alternating beds of clays, marls, gravel and sand.

A series of shot-holes was drilled by the Weizmann Institute of Science along the Sdom highway from Km. 3 to the Potash Plant, in connection with a seismic survey. In several of these wells, water under artesian pressure was struck. Most of these holes stopped flowing when the uncased walls collapsed, but three are still flowing at a rate of 5-10 m^3/hr.

A well drilled by Tahal at one of the locations recommended by Picard and Shiftan, near Ma'avar Sdom (Naqb el Mezell) started in Turonian limestone and struck water at the shallow depth of 23 m. At 28 m depth, asphalt started to seep into the hole and drilling operations were suspended, while additional hydrological information was expected from an oil exploration hole to be drilled close to the well by Israel Oil Prospectors (Mazal No. 1, see below). The water struck has to be considered as originating from a perched horizon.

A shallow hole was drilled in the Nahal Zohar, at another location indicated in Picard-Shiftan's first report. Drilling was suspended here too, because of technical difficulties.

Although situated outside the area dealt within this paper, the three holes drilled by Israel Oil Prospectors Inc., in the plain adjoining the Metzada Hill should be mentioned because of the similarity of geohydrological conditions. These holes, drilled to a depth of 120 m for the double purpose of furnishing structural information as well as of serving as water supply for an oil exploration well, did not strike water. A well drilled by American-Israel Oil Co. 3 km NE of Metzada struck rather saline water under artesian pressure. These results of the Metzada area demonstrate how structural conditions on the mountain border as well as the nature of the basin sediments adjoining it affect the occurrence or absence of groundwater in the basin. On the one hand, the Metzada-horst may well block the passage of groundwater from the mountains into the gravel lenses of the Lisan formation of the basin, whereas the more simple structure farther north facilitates such a passage. On the other hand, the layers of "Foothill age" penetrated by the Metzada wells, almost from the surface downwards have

to be considered much less pervious than the Lisan beds, and may be the reason for the absence of groundwater in the subsoil of the Metzada plain.

b. *Deep Wells.* In search for oil, two large-diameter deep wells were drilled in the area by Israel Oil Prospectors Ltd., Mazal No. 1 and Metzada No. 1. A number of deep structural holes was drilled about ten years ago by the Jordan Valley Exploration Co., in the region between Har Sdom and the mountain cliff as well as on the shore of the Dead Sea near Har Sdom.

Mazal No. 1, situated at Ma'avar Sdom, near Tahal's abandoned water well, starts in Turonian limestone. Water was first struck at approx. 200 m depth (10 m above Dead Sea level) in dolomite, most probably of Lower Cenomanian age. The water rose to approx. 88 m below surface, i.e. approx. 120 m above Dead Sea level. After sealing off this water, a second horizon was struck at 380 m depth (170 m below Dead Sea level) in sandstone of most probably Lower Cretaceous age ("Nubian Sandstone"). This water overflowed the top of the well, and rose under pressure to 12 m above surface, i.e. 173 m above Dead Sea level.

These hydrological data from Mazal No. 1 indicate the existence of two separate aquifers of confined nature, the one in the Lower Cenomanian, the other in the Lower Cretaceous.

Metzada No. 1, situated at the foot of the Metzada hill, started in Upper Cenomanian rocks. At the depth of 340 m, a glauconitic sandstone was encountered (Lower Cretaceous?), and at this depth the drilling mud turned saline. At 630 m, water under artesian pressure was struck in Lower Cretaceous sandstones.

Among the exploration holes drilled by the Jordan Exploration Co., Nos. 7, 8, 9 and 10 are of special geological interest. Whereas the holes Nos. 8 and 10, situated approximately 1 km east of the main mountain cliff, penetrated into rocks of Cretaceous age (Campanian) at a depth of 150 m, the holes Nos. 7 and 9, situated farther east in the 'Amiaz plain, did not reach rocks of Cretaceous — or even Early Tertiary — age at much greater depth (700, resp. 500 m), remaining in Neogene formations. No water was struck in these holes. The geological structure, as evident from surface outcrops and the geological data of the holes is represented in the Cross Section, Figure 4. From this section, it becomes apparent that in this area, west of Har Sdom, no passage of groundwater either from Turonian-Cenomanian limestones and dolomites or Lower Cretaceous sandstones into gravel, sand or sandstone beds of the graben is possible, because of the practically impervious Senonian-Danian chalk and clay beds separating these two series of beds.

In conclusion, it becomes evident that water under confined conditions is found both in the (Lower-) Cenomanian and the Lower Cretaceous of the mountain border, as well as in gravel and sand beds of the Lisan Series in the Ma'avar Sdom area. Because of the more than scanty rainfall and the low permeability of the upper part of the Lisan Series, it seems improbable that these gravel and sand beds are recharged by local rains. The aquifer of the Lisan Series, as found in the Lower

Nahal Zin wells and the springs is therefore recharged most probably by groundwater of the mountain formations. This assumption is supported by the examination of the chemical character of the water from the various sources. The difference in head, as mentioned above, is explained by the extensive outflow in the Lisan area.

The confined water of the gravel beds in the Lisan Series may slowly migrate upwards, either through the little pervious layers themselves, or in fault zones, and give rise to the seepage areas and springs of the Lisan terrains. The fact that seepages are found in the Lisan area, south of Mount Sdom at approximately 50 m above Dead Sea level, as observed by Bentor-Vroman, checks surprisingly well with the observed artesian head of Mazal No. 2 and Zin No. 4.

F. CHEMICAL COMPOSITION OF THE WATER

The study of the chemical character of the groundwater in the Sdom area is based on approximately 30 water samples analyzed in the chemical laboratories of the Mekoroth Water Co. The results are represented in Table I and Figures 6 and 7. It is to be regretted that only the major ions were investigated, and for this reason many questions must remain unanswered.

The salts dissolved in the groundwater of Sdom may originate from the following sources:

a. Salts leached out of the rocks of the mountain formations;

b. Salts leached out of the graben sediments and especially the evaporites associated with them;

c. "Cyclic" salt from the Mediterranean Sea;

d. "Cyclic" salt from the Dead Sea;

e. Direct contact with Dead Sea water, either of the lake itself or trapped within Rocks;

f. Connate water.

Whereas the possibilities a, c and f may affect groundwater also in other parts of the country, possibilities b, d and e are restricted to the graben area. It is because of these possibilities, that salts generally not found in groundwater in considerable quantities, such as magnesium chloride and calcium chloride may become major constituents of the dissolved solids in the Sdom region. The graben sediments contain evaporites such as gypsum and rock salt, well known from surface outcrops at Mt. Sdom. Other salts may exist in depth, although no proof for this has been found so far. The Dead Sea water with its peculiar chemical composition may influence the composition of the groundwater either by direct contact and admixture through porous sediments outcropping on the lake bottom (Herzberg-Guyben principle) or by salt spary. Another possibility is the existence of Dead Sea water that has been trapped within sediments of the graben during periods when the lake level was higher than it is today. In addition, the possibility of contact with connate water of oilfields can not be excluded in view of the widespread occurrence of asphalt seepages.

CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES FROM THE SOUTHERN DEAD SEA BASIN

SOURCE	Sample No.	Geological mode of occurrence	Tot. sol. mg/l	CHLORIDE			SULPHATE			BICARBONATE			NITRATE			SODIUM			MAGNESIUM			CALCIUM			$Cl^- + SO_4^=$	$Ca^{++} + Mg^{++}$	$SO_4^= + HCO_3^-$	$Cl^-/SO_4^=$	Ca^{++}/Mg^{++}	Na^+/Cl^-
				mg/l	Fr°	%	mg/l	Fr°	%	mg/l	Fr°	%	mg/l	Fr°	%	mg/l	Fr°	%	mg/l	Fr°	%	mg/l	Fr°	%	%	%	%			
BOQEIQ SPRING	8198	CONTACT SPRING, CENOMANIAN PERCHED AQUIFER	1680	581.5	82.1	58.1	419.8	43.7	31.0	182.9	15.0	10.6	7.1	0.6	0.42	337.2	73.4	52 0	784	32.3	21 8	143 1	35 7	26 0	89 0	47 8	41 6	1.685	1 11	0890
NAQB-MEZELL - Ma'avor Sedom - "TAHAL"	4311	PERCHED AQUIFER, TURONIAN	2015	822.6	116 1	63.0	120 6	12.6	6.8	685.8	56.2	30.4	—	—	—	471.8	102.7	58.5	136.2	56.0	30.4	104 9	26 2	14 2	69 8	44.6	37 2	9 2	0 465	0.880
" " "	4444	" "	1915	765.9	108.1	69.0	437.5	45.6	29.1	30.5	2.5	1.6	1.1	0.1	—	472 2	102 8	65.8	20.2	8.3	5.3	181 0	45 2	28.8	98 5	34 1	30 7	2 85	5 13	0945
MAZAL No 1 190.2 m	5404	(UPPER?) CENOMANIAN CONFINED AQUIFER	2685	1002.0	141 4	61 8	553 1	57 6	25 5	359.7	29.5	12 9	<1.0	<0.1	—	657.6	143.1	62.8	108.8	44.8	19.6	162 8	40.7	17 8	87.3	37 4	38 4	2 45	0 893	1 012
" " 198.5 m. depth	5406	" "	2680	1010.0	142 6	62 5	553 1	57.6	25.5	[illegible]	28.5	12 5	1.0	0.1	—	667.9	145.3	63.5	122.3	50 3	22 0	132.8	33 2	14 5	88.0	36.5	38 0	2.47	0 660	1 02
" " 298 m	5768	(LOWER) "	3590	1303.1	183.9	61.9	912 0	95.0	32.0	231 7	19.0	6.4	—	—	—	817.7	177.9	59.0	96.6	39.8	13.4	321.3	80.2	27 0	93.9	40 4	38.4	1 92	2.0	0.96
" " OVERFLOW OF WELL 394 m	6749	LOWER CRETACEOUS SST., ARTESIAN CONFINED AQUIF.	3995	1427.0	201 4	60 8	1000.0	104 2	31.5	310.9	25 5	7.7	—	—	—	981.7	213.6	64.0	94.0	38.7	11.7	315.6	78.8	23 7	92 3	35.4	39 2	1 930	2.038	1.06
" " 387 m	6747	" "	3805	1400 0	197.7	63.0	915.3	95.4	30.5	253.0	20 7	6.4	—	—	—	1003.0	218.3	69.8	66.6	27.4	8.75	272.7	68.1	21.9	93.5	30.65	36 9	2.075	2.485	1.105
MAZAL No. 2 66-96 m	7293	LISSAN SERIES ARTESIAN, CONFINED AQUIFER	2930	1124.0	158.6	64.0	637.9	66.5	26.5	277 4	22.7	9.05	—	—	—	698.9	152.1	61.5	112.8	46.4	18.6	197.5	49.3	19 9	90.9	38 5	35.5	2.78	1 06	0 96
" "	12846	"	2900	1117.0	157 64	64.0	623.1	64.92	26.5	274.3	22.5	9.15	—	—	—	694.2	151.06	61.5	110.5	45.5	18.5	194 2	48.50	19.8	90.5	94 0	35 65	2 43	1 066	0 960
NAHAL ZIN No.1 30 m	4373	GRAVELS (RECENT)	2700	1042.4	147 1	64 0	609 1	63 5	27 2	231.7	19.0	8 3	—	—	—	595 5	129.6	51 2	122.6	50.5	22.0	198.4	49.5	21 8	91.2	43.8	35.5	2.32	0.892	0.880
" 39 m	4707	"	2490	964 4	136.1	64 5	605.4	63.1	30 3	118 9	9 7	4.7	T R	A C	E S	597.9	126.2	60.8	104.5	43.0	20.6	159.2	39.7	19.1	94.8	39.7	35.0	2.15	0 925	0.925
"	5580	GRAVELS (RECENT) LISSAN SERIES (CONFINED AQUIFER)	2600	992.8	140.1	63.5	562.0	58 5	26.5	268 2	22.0	10.0	5.3	0.4	0 18	578.4	125.8	57.0	114.4	47.1	21.4	192.8	48.1	21 8	90.0	43.2	36.5	2.38	1.02	0 90
"	12841	"	2665	1010.5	142.63	63.2	586.9	61.14	27 2	268.2	22.0	9 72	2.7	0 21	—	583 5	126.98	56 2	119.4	48.03	21.3	204.1	50 97	22.4	90 4	43 7	36 92	2.33	1 058	0.880
NAHAL ZIN No.2	8927	LISSAN SERIES "STATIC" WATER	8700	4503.0	635.6	84.0	1037 0	108.0	14.2	121.9	10.0	1.32	—	—	—	2291	498.6	66.0	368.6	151.7	20.0	413.6	103.3	13 7	98.2	33 7	15 5	5 62	0 682	0 785
NAHAL ZIN No.3 16.50 m	6172	GRAVELS (REC.) LISSAN SERIE. SEMI-CONFINED AQUIFER(?)	2350	939.6	132.6	66 0	489 7	51 0	25.4	204.2	16 7	8 3	3.5	0.3	0.15	500.8	108 9	50 5	118.3	48.7	23 8	172.4	43.0	21.5	91.4	55 3	33.7	2 60	0.885	0 815
" " " 70 m Static water	6830	LISSAN SERIES INCL. GRAVELS	3660	1702.0	240.0	76.0	557 6	58 1	18 4	228 6	18 7	5 9	—	—	—	839 5	182.6	58 5	178 4	73.4	23 1	244.5	61.1	19 3	94.4	42.4	24 3	4 15	0.84	0.760
" " " Pumping test	9294	LISSAN SERIES, CONFINED AQUIFER (ARTESIAN)	2540	1007.0	142 1	66.5	582.7	60 7	27.5	134 1	11 0	5.2	0 7	0.06	—	587.8	127.9	59 8	111.2	45.8	21.5	161.1	40.2	18.8	94 4	40.3	32.7	2.32	0.880	0.899
" " "	12842	"	2610	992 6	140.13	63.2	579.5	60.37	27 1	265 2	21.75	9 78	3 5	0.29	—	551.6	120.04	54.0	123.9	50 98	22 8	206 3	51.52	23.2	90.3	46 0	36.9	2 33	1 012	0.860
NAHAL ZIN No.4 35 m	8431	LISSAN SERIES, ARTESIAN, CONFINED AQUIFER	2865	1120 0	158 1	65.2	614 9	64 1	26.5	243 9	20.0	8 25	1 4	0 1	—	736 7	160 3	66.0	119 0	49 0	20 2	132.3	33.0	13.6	91.7	33 8	34 7	2.16	0 675	1 011
" " "	12843	"	4835	2322 0	327.79	78 5	619 0	64 49	15 5	286.5	23 5	5 64	—	—	—	1336.2	290.78	71.5	171 3	70 47	16.9	218.4	54 53	13 1	94.0	30.0	21.14	5 15	0.875	0 890
EIN TAMAR (Arus)	8690	LISSAN SERIES, FAULT ?	2530	957 3	135 12	63.0	574 5	59 9	27 6	253 0	20 75	9.65	0.7	0.06	—	513 7	111.79	51 5	127 2	52 36	24 25	206 8	51.64	24.0	91 8	48.25	37.2	2 26	0 98	0.818
" " "	12845	" (ARTESIAN SPRING)	2525	939 6	132 62	61 3	581 9	60 63	28.0	280 4	23.0	10.6	2.7	0.21	—	457 0	99.46	46 0	135.8	55 91	25 8	244.6	61.09	27.9	89 3	53 7	38 6	2 18	1 09	0 750
EIN HAQIQAR (Belda)	8691	LISSAN SERIES, FAULT ?	2750	1099 0	155 1	66 0	574 5	59 9	25 25	250 0	20.5	8 7	—	—	—	562.9	122 5	52.0	137 2	56 5	24.0	226 4	56 5	24 0	91 8	48.0	33.9	2 59	1.0	0 79
"	12844	" (ARTESIAN SPRING)	2835	1152 0	162 64	67 0	572 9	59 69	24 4	253.0	20 75	8 5	2.7	0.21	—	575 7	125.29	51 2	136.9	56 36	23 2	246 8	61 64	25.3	91 4	48 5	32 9	2 72	1 095	0 770
SHOT-HOLE Km. 103	7831	LISSAN SERIES, CONFINED AQUIFER (ARTESIAN)	11350	6382 0	900 8	89 0	843.6	87 9	8.6	213 4	17.5	1 73	—	—	—	2740.0	596 2	59.6	602 1	247.8	24 7	651 1	162 2	16 2	97.6	40.9	10.3	10 25	0.655	0 660
"	7833	"	11740	5265.0	743 1	75.8	2206.0	229.8	23 4	152.4	12.5	1.2	—	—	—	2322.0	505.4	51 5	534 1	219 8	22 2	1042.0	260 2	26 5	99.2	48 7	24.6	3.25	1.185	0 680
"	7832	"	6940	3590 0	506 7	83 0	765 5	79 7	12 9	274.3	22.5	3 7	—	—	—	1638.0	356 4	58.8	350.1	144.1	23 8	434.1	108 4	17.9	95.9	41.7	16.6	6.85	0.752	0 630
SULPHUR SPRINGS 6 m	6957	FROM GRAVEL TERRACE; PROBABLY CONN. WITH FAULT	50400	32975.0	4654 0	98 5	666 7	69 5	1.46	276 8	22 7	0.47	—	—	—	7955.0	1730.8	36 5	5353 0	2203 0	46.5	3167.0	791 0	16 7	99 96	63.2	1.8~	67 0	0.360	0 72
" "	7023	"	68950	45470.0	6418 0	98 5	691 0	72 0	1.1	137.2	11.2	0.17	—	—	—	11091.0	2415 2	37 0	7361 0	3030.0	46.5	4230.0	1056.0	16.1	99.6	62.6	1.3	89.3	0 495	0 378
MAZADA No. 1 636 m	8408	LOWER CRETACEOUS SANDSTONE	5580	1624.0	231 7	51 5	1794.0	187.0	41 5	384.1	31.5	7.0	—	—	—	1519.0	330.7	73 0	106.1	43 7	9.7	303 6	75 8	16 6	93 0	26 3	48 5	1 238	1.735	1 430
" " "	8586	"	6470	1808.0	255 2	49 0	2338.0	243.5	47.0	244 0	20.0	3.88	—	—	—	1249.0	271.8	52 5	110.5	45 5	8.7	808.9	202.0	39 0	96.0	47 7	50 8	1.213	4.45	1 420
MAZADA structure hole 328 m	9353	"FOOTHILL" SERIES	153500	97506.0	13762.0	98.0	1786 0	186.0	1.3	243.9	20 0	0 7	—	—	—	13762.0	7468 0	53.0	10035.0	4130 0	29 5	9491.0	2370.0	18.0	99.3	47.5	2.0	7.72	5 74	0 542
DEAD SEA WATER			272480	177250.0 Br=4180	25000 0	98.48 Br=1.04	1160 0	120.0	0.48	—	—	—	—	—	—	34350.0 K=5900	7450 0 K=757	28.69 K=2.9	33400.0	13800 0	52 78	16300.0	4050.0	15.63	98.96	68.41	~0.5	210.0	0.293	0 295

TABLE I

mg/g milligram/liter
Fr^0 French degrees = 5 × milliequivalent

% percent of total anions or cations

It is therefore impossible to assume the existence of any "normal" groundwater ($Cl^- = Na^+; SO_4^= + CO_3^= = Ca^{++} + Mg^{++}$) in the Sdom area, and an "abnormal" composition of water is not necessarily proof for the activity of base-exchange processes. On the other hand, the widespread occurrence of clays both in the mountain formations and among the graben sediments should provide plentiful possibilities for base exchange affecting the groundwater coming into prolonged contact with them, during the process of slow percolation under confined conditions.

Apart from the influence of carbonic acid on pyrites, forming sulphuretted hydrogen, this gas was may also be formed by reduction of sulphates; the bases would then form hydroxides which, in due course, would form bicarbonates and carbonates. Reduction of gypsum by hydrocarbons was considered by Picard as one of the processes forming the sulphur nodules found in the Lisan beds. Such processes, however, are probably more of biochemical than of purely chemical character. Anyhow, this is another possibility of abnormal changes in groundwater*. Hydrocarbonic material, mentioned by Picard from the Lisan beds, of Metzada, has been found during our present survey in the form of asphalt-saturated gravel lenses in the Lisan beds also near Ma'avar Sdom.

In general, the groundwater in the Sdom area is rather brackish. Total salinity varies between 1700 and 69,000 mg/l of total dissolved solids. As shown in Figure 6 all water samples are of the sulphate/chloride type, and poor in bicarbonates. There is a considerable variability in the ratio calcium-magnesium/sodium-potassium.

According to their chemical characteristics as well as their geological-geographical distribution, the results of the analysis can be grouped as follows:

1. Water from the phreatic contact aquifer of the Turonian-Upper Cenomanian of the Mountain Area.
   Boqeq spring.
   Tahal Well at Ma'avar Sdom.
2. Confined aquifer of the (lower-) Cenomanian of the Mountain Area:
   Mazal No. 1, 200 m depth.
3. Confined aquifer of the Lower Cretaceous (-Jurassic) Sandstones of the Mountain Area:
   Mazal No. 1, 600 m depth.
4. Confined and semi-confined aquifers of the Lisan Formation in the Lower Nahal Zin region:
   Nahal Zin wells Nos. 1, 2, 3, 4;
   Mazal No. 2;
   'Ein Tamar-'Ein Haqiqar springs.
5. Confined aquifer of the Lisan formation near Potash Plant :
   Seismic shot holes along Sdom highway.
6. Confined aquifer of the Lower Cretaceous-Jurassic sandstones, Metzada Region:
   Metzada No. 1.

* The extremely low sulphate content of the water from Nakb Mezell, along with the relativeli high bicarbonate content could find its explanation in this manner.

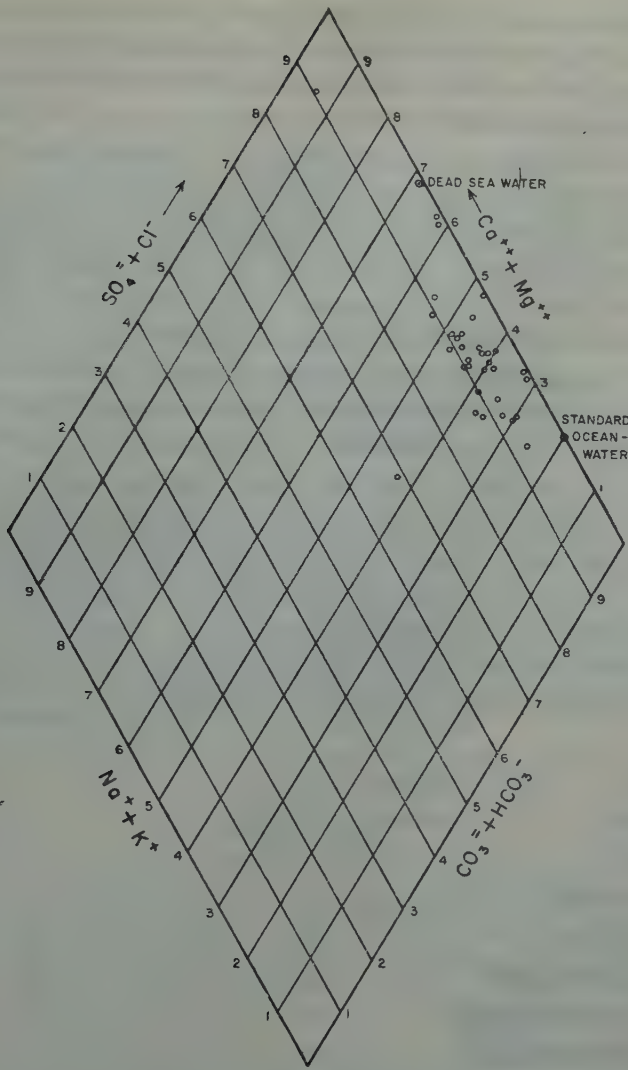


FIGURE 6

General chemical characteristics of 34 water samples from the southern Dead Sea basin

7. Sulphur springs on the Boqeq shore.
8. Dead Sea water (for comparison).

All the water samples from the sources belonging to one of these groups show their distinct chemical characteristics.

1. *Water from the phreatic contact aquifer* (*Turonian-Upper Cenomanian*)

The water from this phreatic aquifer of the mountain formation is characterized by a comparatively low total salinity. All other factors seem to vary rather widely. The considerable nitrate content of the water of the Boqeq spring may be due to

decomposing organic material in the seepage area. The unusually high bicarbonate hardness of one of the samples from the Naqb el Mezell well may be related to the occurrence of hydrocarbon material, causing the reduction of a great part of the sulphates, as explained above (p. 42).

2. *Mazal No.* 1. *oil well, upper confined aquifer*

The two samples from 190 and 199 m depth respectively, are very similar in total salinity (2680 mg/1). The percentage of sulphate plus chloride among the anions (87-88) is rather low when compared with the other groups. Sodium exceeds chloride very slightly and chloride exceeds sulphate by a factor of 2.5. A small amount of nitrate was found. Comparing the percentages of calcium-magnesium with those for sulphate-bicarbonate, it appears that this is almost "normal" water and that neither extensive base-exchange processes nor addition of "abnormal" salts have affected this water. Magnesium exceeds calcium by 1.1 to 1.5.

3. *Mazal No.* 1 *oil well, lower confined aquifer*

Two samples, originating from this aquifer are available. Here, total salinity is higher (3800-4000 mg/1) than in the upper aquifer. Chloride-sulphate percentage is also higher (92-94%). Sodium slightly exceeds chlorine (1.0-1.1) just like in the upper aquifer, but calcium exceeds magnesium by a factor of 2.0-2.4. Sulphate-bicarbonate exceed in these samples magnesium-calcium considerably and one may assume an exchange of some magnesium for sodium.

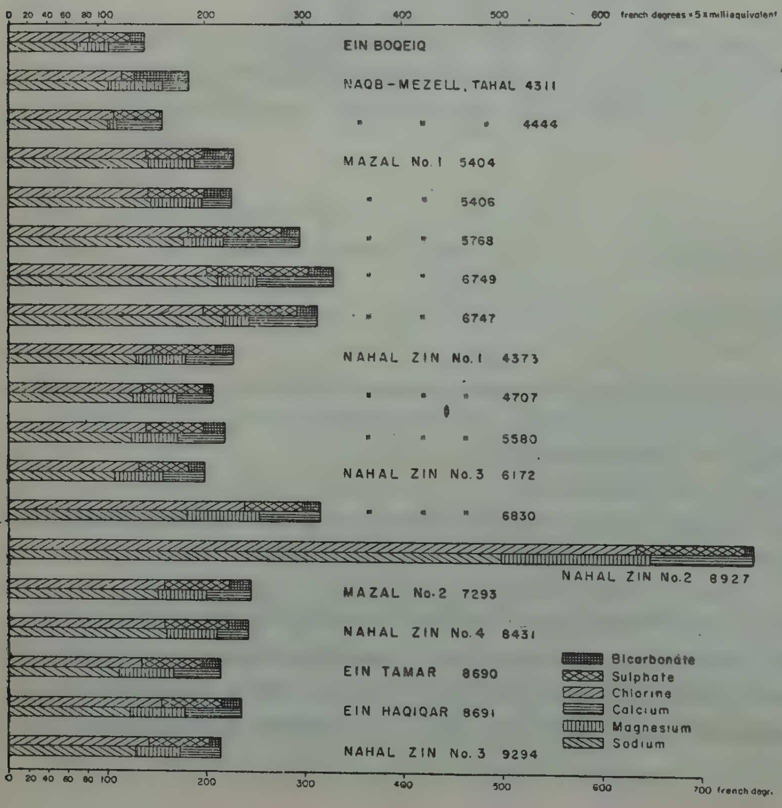


FIGURE 7

Ion-relationship and concentration of 19 water samples Sdom region

The sample No. 5406 from a depth of 292 m is somewhat problematic in so far as at this depth the hole was still in Lower Cenomanian, but the water resembles more closely the type met in the lower aquifer. Total salinity is between the two types (3600), but closer to the figure for the lower aquifer, and the same holds for several other characteristics. A possible explanation for these facts may be given again by the structural conditions. Water from the sandstone aquifer of a more elevated block in the West may have penetrated into the lowermost beds of the Cenomanian dolomites, as shown in the cross section, (Figure 4).

4. *The aquifers of the Lower Nahal Zin*

Twelve samples from various sources in this region were available. Not including the static water from Nahal Zin No. 2, and the one from 70 m depth in Nahal Zin No. 3, taken before the pumping test, a remarkable uniformity prevails. Total salinity varies between 2350-2930 mg/1. Chloride and sulphate together account for 90-95% of the anions. Chloride exceeds sulphate by a factor of 2.1-2.8, and chloride exceeds sodium in all cases but one (Zin No. 4). Calcium and magnesium in all cases exceed sulphate-bicarbonate considerably.

It has been suggested above that the groundwater of the lower Nahal Zin originates from the mountains in the West. This has been explained on the basis of geological structure and hydrological data. Here, this possibility will be discussed as far as the chemical character of the water is concerned.

TABLE II

Total Salinity in mg/1

Source	Salinity
Mazal No. 1, Ceno.	2680
Mazal No. 1, Nub. sst.	3800 — 4000
Zin No. 1, 30 m	2700
Zin No. 1, 35 m	2500
Zin No. 1, ?	2600
Zin No. 3, 18 m	2350
Zin No. 3, 70 m	3660
Zin No. 3, pump. test	2540
Zin No. 2, (static)	8700
Mazal No. 2,	2930
Zin No. 4	2865
'Ein Tamar	2530
'Ein Haqiqar	2750

A comparison of total salinity figures for the Nahal Zin aquifer and the two aquifers of Mazal No. 1, gives the following conclusions :

It appears that in several samples from Nahal Zin, the total salinity is below the lowest salinity encountered in the upper aquifer of Mazal No. 1. The difference, however, is rather small.

Such cases are the samples from Nahal Zin No. 3, 18 m depth and from the pumping test, Nahal Zin No.1, 35 m depth and 'Ein Tamar. Slightly higher salinities occur in Mazal No. 2, Nahal Zin No. 4 and No. 1 (in part). The much higher salinities of Zin No. 2 and the one sample of Zin No. 3 cannot be compared here because they represent non-flowing (static) water.

In order to explain these facts, the following possibilities have to be considered :

a. Although most of the groundwater in the lower Nahal Zin originates from groundwater in the highlands, there may be a certain addition of water from surface run-off, especially from the frequent floods of Nahal Zin. Thus, salinity especially in water from shallow depth may become less than the minimal salinity in the Mazal No. 1 aquifers. In fact, the first three wells in the Nahal Zin were drilled in search after such subsurface run-off.

b. Groundwater passings through, or coming into contact with the sediments of the Dead Sea basin may easily pick up additional salts from various sources, as explained above, and total salinity may increase.

c. Assuming that the structural conditions of the graben border are as described above (p. 31-34), the deeper pervious layers of the Lisan (and other graben) sediments may be fed from the more saline Nubian sandstone aquifer. There is, moreover, the possibility of the water from the two aquifers of the mountain area being mixed near the fault zone, or in permeable beds of intermediate depth in the basin. The relation of the ions as found in the Zin wells does suggest such a possibility.

Although the analysis available do not permit far-reaching conclusions, there is no reason to assume contamination by Dead Sea water in this part of the lower Nahal Zin.

The analyses clearly show that the water of the springs 'Ein Tamar and 'Ein Haqiqar as well originate from the same aquifer that appears in the wells. There can be no doubt that even the water found at shallow depth in Nahal Zin Nos. 1 and 3, in gravels reported to be without clay intercalations from the surface to 40 m depth, originates from the same confined horizon. It has already been suggested above (p. 40) that this water may rise from the confined horizon along fault lines or through semi-pervious beds, losing by this upward seepage part of its original head and filling, as secondary unconfined or semiconfined water, shallower aquifers.

5. *Confined aquifer near Potash Plant*

Although this aquifer is identical with the one of the lower Nahal Zin as far as the geological character is concerned, the chemical composition is completely different. Three water samples from seismic shot-holes were examined. Total salinity is much higher than in the former groups (7000-12000), chloride and sulphate amount to almost 100% of all the anions, chloride exceeds sulphate by a factor of 3-10, and sodium falls short of chloride by a factor of 0.6-0.7. This, as well as the fact that calcium and magnesium far exceed sulphate and bicarbonate, in-

dicate either an admixture of calcium chloride (and/or magnesium chloride), or a far advanced process of exchange of sodium against calcium and magnesium. The strongly increased salinity points clearly to the first possibility. The admixture of these salts, as well as of additional sodium chloride, may be explained by the existence of deposits of such salts at comparatively shallow depth, or flushing out of ancient Dead Sea water trapped in various horizons of the Lisan sediments in this region.

Small springs originating in the Lisan formation in almost all gullies west and south-west of the Potash Plant are also very strongly saline and may originate from the same horizon. No analyses, however, were available ('Ein Heimar).

6. *Confined aquifer of the Metzada No. 1 Well*

Two samples of water from the Lower Cretaceous (?) series of sandstones and shales of the Metzada No. 1 oil exploration well were examined. Apart from the rather high total salinity (5600-6500) the two samples differ considerably. The differences may be explained, however, by the a. m. effect of sulphate reduction and resulting increase in bicarbonate due to the presence of hydrocarbonic material. There can be no doubt that admixture of Dead Sea water is not, or only in part, responsible for the high salinity, because of the strong prevalence of sodium over chlorine, of calcium over magnesium, the chloride/sulphate ratio close to 1 (1.2) and the comparatively (for the region) low combined amount of sulphate and chloride (93-96%), (the Dead Sea water being practically without bicarbonates).

7. *Sulphur springs of the Boqeq shore*

These springs originate very close to the Dead Sea shore, out of gravel beds, only very little above lake level.It has been mentioned above, that they may arise along a fault line. Their total salinity being as high as 50,000-60,000 mg/l as well as all other chemical characteristics strongly suggest admixture of Dead Sea water, or of water of a composition similar to that of Dead Sea water. The comparatively low sulphate content, the high figures for magnesium and chlorine, as well as the very low calcium/magnesium and sodium/chlorine ratios, all point in this direction.

But still, total salinity is not more than $^1/_5$ of Dead Sea salinity, and considerable quantities of comparatively fresh groundwater from the mountain area must therefore form a part of the total yield of these springs.

CONCLUSIONS

From the geological structure, the survey of the water resources and the examination of the chemical character of the groundwater, the following conclusions can be arrived at for the hydrogeological regime of the Sdom area:

An artesian-subartesian aquifer exists in the Sdom area. This aquifer consists of gravel and sand deposits of the Lisan formation, intercalated and covered by clays and marls. It is replenished continuously by passage of groundwater from Northern Negev/Southern Judean highlands into these previous beds of the Lisan formation. These either wedge out toward the centre of the basin or are cut off by

young faults affecting these beds. The groundwater is discharged in springs and extensive seepage areas probably connected with fault lines. Thus, shallower pervious horizons, and even the recent gravel beds of the Lower Nahal Zin, may be replenished by water from below and become "secondary aquifers". During upward migration, pressure becomes reduced, and the water in the shallower pervious beds is under semi-confined or even phreatic conditions. Here, admixture of strom-water run-off from intermitent streams becomes possible and a slight reduction of the original total salinity may occur. Because of the variation in resistance the water has to overcome in different localities, static water levels in shallow gravel beds should not lead to any far-reaching hydrological conclusions. The pumping test of the well Nahal Zin No. 3 has proved the confined nature of the aquifer, even in this non-flowing well.

No sufficiently based figures for the total groundwater discharge can be given so far. The total evapotranspiration of the seepage areas from 'Ein Haqiqar to the Potash Plant, in addition to the yield of all the springs should be equal to that discharge.

No proof for the existence of a salt water/fresh water interface between Dead Sea water and the relatively fresh groundwater has been found. It is therefore highly doubtful, if the Ghuyben-Herzberg principle affects the area around the Dead Sea shore in the Sdom region. Neither can the Lisan formation, forming the Dead Sea bottom near Sdom — or other basin sediments — be compared to the porous sand or sandstone aquifer to which that principle can be applied.

Various other factors, such as evaporite sediments in the Tertiary-Quaternary formations of the vift may be the reason for the high salinities encountered in several wells and springs.

Therefore, groundwater of relatively good quality should be expected in the zone of the graben border, where it can be obtained directly out of the Cenomanian-Turonian limestones and dolomites. Moreover, these formations represent good prospects as fas as yields are concerned because of their highly carstic character. The ideal solution would be to exploit a maximum of groundwater in this area. Thus, the artesian head in the Sdom area would be lowered, and the saline water lost today mainly by evaporation-transpiration would be used while still comparatively fresh.

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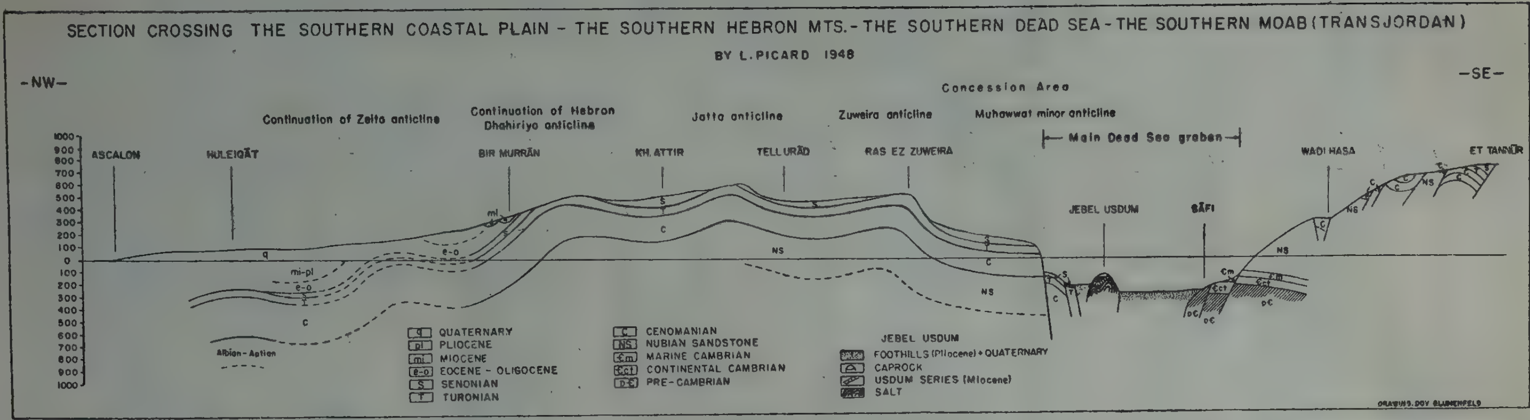

Note added in proof:

Since this paper was received, more wells have been drilled in the Dead Sea area, and more hydrogeological information has been made available. A new water-well, drilled near the old Mazal well of Tahal, was abandoned while practically dry. The reason seems to be the extensive asphalt occurrence in this region, which also created serious difficulties for the operation of the percussion rig. Two more wells for oil prospecting purposes were drilled, one on the west fllank of Mt. Sdom, the other in the Lisan-terrain near the Potash Plant. Artesian water was found in both wells. The chemical composition was peculiar in so far as the potash content was considerable. Another water well has been completed recently near Ma'avar Sdom on the foot of the main cliff. A rich supply of water (300-400 $m^3/_4$ per 1 m drawdown) was struck. The salinity is similar to the one found in the Lower Cenomanian aquifer of Mazal No. 1.

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APPENDIX

Details of bore-holes in the Southern Dead Sea Region

1. Naqeb-Mezell (= Maavar Sdom) (Tahal)

Loc.: 1799/0433 approx.
Elevation: — 239 m (approx.).
Water struck: 23 m from surface,
Static water level: (of this horizon) 21 m from surface, = —260 m abs.
Description of strata:

0 — 0.80 m fine chalky material, with broken pebbles
0.80—2.00 m broken pebbles of flint and dolomite
2.00— 6.50 m broken pebbles of flinty dolomite and hard dolomite.
6.50— 7.50 m hard dolomite
7.50— 9.00 m hard dolomite, broken up, with asphalt
9.00—11.00 m dolomite
11.00—18.50 m dolomite, asphalt
18.50—38.00 m dolomite, asphalt

Formation : Turonian

2. Mazal No. 1 (Lapidot)

Loc.: 01795/04450
Elevation : — 185 m (approx.)
Water struck : 200 m, 380 m from surface
Static water level : 88.50 m, from surface, 12 m above surface resp.
Description of strata (courtesy "Lapidoth" Ltd.) :

0— 33 m (approx.) Turonian
33—374 m Cenomanian
374— m Nubian Sandstone

3. Mazal No. 2 (Lapidot, slim hole)

Loc : 18220/04440
Elevation: —345 m (approx.).
Water struck : 47 m from surface
Static water level : 20 m above surface
Total depth : 120 m
Flowing yield : 70 m^3/hr.
Description of strata : not available
Formation drilled : Lisan series

4. Nahal Zin No. 1 (Tahal)
Loc : 1831/0447
Elevation : — 358.0 m
Water struck : 24 m (?)
Static Water level: 24 m
Yield : 110 m^3/hr. per 1 m drawdown
Description of strata (samples not available):
0—39 m gravel
39—42 m clay
Formation : Alluvian and Lissan Series:

5. Nahal Zin No. 2. (Tahal)
Loc.: 1828/0451
Elevation : ?
Static water level : 21 m from surface
Description of Strata:
0—20 m gravel
20—37 m clay
Formation : Alluv. and Lisan Series

6. Nahal Zin No. 3 (Tahal)
Loc.: 1835/0447
Elevation : —364.30 m
Water struck : 16.30 m
Water level : 16.30 m
Yield : 300 m^3/hr. per m drawdown
Description of strata :

6— 3.40	gravel, sand, silt	Alluv.?
3.40—16.90	gravel	
16.90—18.00	sand and gravel	
18.00—20.50	gravel	
20.50—28.00	gravel and sand	Lisan series
28.00—30.50	yellow marl	
30.50—70.00	gravel	

7. Nahal Zin No. 4 (Tahal)
Loc. : 1825/0454
Elevation : — 348 (approx.)
Water struck : 21 m
Static water level : above surface
Flowing yield of 47 m^3/h
Description of strata :
0— 13.20 clay gravel, boulders
13.20— 14.80 very chalky marl, some small gravels
14.80— 19.00 marl
19.00— 20.60 dark-grey clay with carbonized plant remnants

20.60— 31.60	marly chalk
31.60— 34.30	gravel (medium and small)
34.30— 53.70	light-grey clay and marl
53.70— 55.20	grey-coloured sand (fluviatile)
55.20— 57.50	sand, loamy
57.50—	grey clay and marl
63.00— 64.00	small gravels and (fluviatile) sand
64.00— 67.80	medium-sized gravel
67.80— 80.50	grey clay and marl
80.50— 82.80	white-yellow chalky marl
82.80— 90.00	very fine sand with small gravels
90.00— 94.00	fine loamy sand
94.00—106.70	white-grey marly clay
106.70—110.50	gravel
110.50—118.00	coarse sand and small gravel
118.00—122.50	medium sized sand
122.50—(123.00)	dark grey clay

Formation drilled : Lisan (and "Samra?)

8. STRUCTURAL HOLE No. 8 (Jordan Exploration Co.)
   Loc.: 1817/4965
   Elevation : —262 m
   Formations drilled :
   0—163 m "Foothill Series"
   163 (or 120?)—241 m Senonian
   No water
9. STRUCTURAL HOLE No. 9 (Jordan Exploration Co.)
   Loc.: 1825/4970
   Elevation : —310 m
   Formations drilled :
   0—500 m "Foothill Series", no water
10. STRUCTURAL HOLE No. 7 (Jordan Exploration Co.)
   Loc.: 18225/48250
   Elevation : — 316 m
   Formations drilled :
   0—700 m "Foothill Series", no water
11. STRUCTURAL HOLE No. 10 (Jordan Exploration Co.)
   Loc.: 1818/5020
   Elevation : — 269 m
   Formations drilled :
   0— 80 m Lower "Foothill"
   80—125 m Danian
   125—155 m Maestrichtian
   No water

AN EXTINCT WADI SYSTEM IN THE SYRIAN DESERT

H. E. Wright, Jr.
University of Minnesota, Minneapolis, Minnesota

INTRODUCTION

In the deserts of North Africa the pluvial periods of the Pleistocene are recorded by the growth of lakes and springs in oasis depressions, and Gautier describes a great extinct wadi system in the now rainless Sahara. In the deserts of the eastern Mediterranean, however the records of former pluvial periods have not been fully explored. Picard (1943) identified two major pluvial periods in the Pleistocene deposits of the Jordan—Dead Sea lowland, but observations on the Arabian Plateau proper have been scattered.

One major landscape feature of the Syrian Desert, however, may be a relic of a past climate—the wadi system which leads from the Arabian Plateau proper down to the Mesopotamian Lowland. The development of a unique transverse banding of vegetation and soil on the wadi bottoms suggests that there has been little disrupting surface water flow of significance in these wadis for a very long time. The writer had opportunity to examine these wadis at several places in southeastern Syria, Iraq, and the eastern arm of Jordan while attached to the Iraq-Jarmo Project of the Oriental Institute*, and offers a description and tentative explanation of the transverse stripes.

SETTING OF THE WADIS

Much of the Arabian Plateau is a rocky or sand-covered wasteland with scattered undrained depressions and with aimless drainage. The northeastern margin, however, is marked by a series of broad steps separated by broad intricately dissected scarp zones. The steps are controlled in part by the structure of the bedrock — thin-bedded limestone and sandstone dipping very slightly northeastward —, but in part they represent successive pediments which have worked back from the intermittently rejuvenated Euphrates River in the Mesopotamian Lowland. The steps and scarps are traversed by roughly parallel wadis. Within the scarp zones

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there are many dentritic tributaries which gather into single northeast-flowing major wadis that either lose themselves on the broad step below or traverse the step completely and pick up another set of tributaries in the next scarp zone. Few major wadis actually reach the Euphrates River at the present time — only the Wadis Hauran, Hazini, al-Ubayyid, and al-Kharr cross the entire distance from plateau proper to lowland.

DESCRIPTION OF STRIPES

On aerial photographs the wadi bottoms show a remarkable pattern of transverse stripes which superficially resemble either transverse sand dunes or broad ripples on a stream bed. The stripes are barely visible on the ground and it is no wonder that no notice has been made of them by such travelers who have described the landforms of this area. With the air photographs as a guide, however, one can easily follow the pattern of narrow dark vegetation and broader light relatively barren stripes. (Figure 1).

The stripes are invariably oriented transverse to the trend of the wadis. They are either straight, slightly sinuous, or concave downstream as they extend across the bottom, and are in all cases gently curved downstream at the ends as they taper into the lateral slope.

The spacing of the dark stripes ranges from 25 feet in the steeper headwater wadis (slope a few percent) to 400 feet in the broad flatfloored, gently sloping areas (slope less than 1 percent). The dark stripe starts abruptly on the upstream margin and fades out downstream into the light stripe. In general the dark stripe is ¼ to ¾ the breadth of the light stripe in the steeper wadis, but in the flat wadis may be only 1/20th.

The vegetation growth that produces the striping reflects the microrelief. The troughs are generally only 1 or 2 inches deep, and can hardly even be identified on broad wadi bottoms. In the steeper wadis, the profile of the wadi bottom shows a minute terrace form. The toe of each step (tread) is marked by a linear ridge, and the trough (with vegetation) is marked by a linear ridge, and the trough (with vegetation) begins immediately downstream at the upstream edge of the next step below.

The vegetation of the dark stripe consists of grasses and herbs which decrease in density and size as the stripe fades out downstream. The light bands bear only scattered grass roots (from recent wet years) and a discontinuous lichen crust.

The active features which produce the microrelief and thus the vegetation stripe are the linear ridges ("boils") just upstream from the dark stripes. The ridges are generally about 2 feet broad and an inch or two high. They are red-brown and more clayey than the adjacent buff silty areas. They are barren of vegetation except for patches of lichen, perhaps because of afflorescence of salt. They seem to

have been raised by swelling of the clay-rich soil. In cases there is a concentration of small stone fragments at the downstream base of the ridge,— stones which have presumably been lifted by the heaving of the boil and then have migrated to the base.

The soil in the striped wadis is not alluvium, but is a stony silt developed *in situ* by weathering of limestone. The soil is a few inches thick, and grades down into impermeable breccia consisting of cemented fragments of limestone weathered from the underlying bedrock. The soil under the "boils" is more clayey, and less stony than that under the troughs. The frequency and size of stones which form the desert pavement in this area depends on the slope and the proximity to outcrops. In the broad flat-floored wadis the stone fragments on the surface are small and scattered, because they have had a longer period to be reduced by weathering in the underlying soil.

ORIGIN OF STRIPES

The transverse vegetation stripes as visible on air photographs suggest either transverse sand dunes formed by wind moving down the wadis, or giant ripples formed by floods of water.

An eolian origin is impossible because (1) the wadis are too shallow to permit channeling of the wind downstream; (2) the transverse stripes are not made of sand but of stony silty soil developed *in situ;* (3) the stripes have a height of only 1—2 inches.

A fluvial origin is impossible because (1) the stripes are not formed in alluvial sand or gravel but in soil developed *in situ;* (2) the stripes are concave downstream, whereas upstream concavity would be expected in fluvial ripples where water velocity is retarded toward the margin of a stream; (3) although heavy rainfall and flash floods do occasionally occur in this region, it is difficult to visualize sheet floods of such magnitude as to produce ripples with an amplitude as great as 400 feet on the larger wadis, or as great as 25 feet even to the passes at the heads of the smaller wadis — and yet with an amplitude of only an inch or two; (4) the Wadi Hauran and other major wadis have the usual transverse striping in their upstream portions, but downstream the striped wadi floors are entrenched by a single axial gully which records the type of erosional work that does result from the occasional flash flood.

The key to a satisfactory hypothesis for the formation of the transverse stripes is an explanation of the linear ridge or "boil" which maintains the microrelief. The "boil" appears to represent localized weathering of limestone to a clayey material subject to swelling. Of especial significance is the fact that the stripes (including the "boils") curve downstream at the margins of the wadi floors, and thus closely record the contours of the wadi.

The linear "boils" are tentatively explained by a process of subsurface movement of soil water. The water which infiltrates during the infrequent rains is held to shallow depth by the impermeable breccia subcrust. The water moves in the subsurface along this contact, following the available slope of the land. It thus becomes concentrated beneath the wadi floors. For some reason not as yet understood the water in its subsurface movement must be "dammed up" at regular intervals to produce the transverse zones of concentrated weathering, clay formation, and swelling. The "dams" are more closely spaced on the more steeply sloping wadi bottoms. The curvature of the stripes at the edges of the wadis are a result of the merging of the side slopes into the wadi slope.

No similar soil structure or resulting pattern has been reported from desert regions before, as far the writer is aware. The transverse striping resembles in a way the solifluction terraces in arctic regions where impermeable permafrost inhibits deep infiltration of water; solifluction, however, is a form of mass movement, for which there is no evidence in the desert stripes. One other comparison may be made with the proposed formation of small mounds (often called mima mounds) in the Sacramento Valley of California. According to Nikiforoff (1941) these mounds may result from the local rise of subsurface water at random points; there is no linearity to the mounds, however, and little other similarity.

CONCLUSIONS

Recognition of the transverse soil stripes in the wadi floors of the Syrian Desert as the result of long-time stable soil formation implies that the wadis have not carried a major flow of water for a very long time. The absence of alluvium on the wadi floors supports the conclusion. Yet the wadi system must have been formed by running water aided by sheetwash.

It is here suggested that the wadi system was formed during a pluvial phase of the Pleistocene, and since that time has been essentially extinct. Such surface wash as does occur at present is not sufficiently vigorous to destroy the stripes of soil and vegetation. Only the downstream portions of the major wadis show axial gullies indicative of the work of modern streams.

The period of wadi formation cannot be dated precisely at the present time. Circular stone structures with associated flint artefacts (Paleolithic?) occur in one area northeast of Rutba on the slopes close beside the striped wadi floors, so the wadis are at least as old as these structures. The wadi system appears to be masked by a great stretch of wind-blown sand along the Wadi Amij about halfway between Rutba and Hit. The age of this sand body has not been determined. The extinct wadi system of the Syrian Desert, if correctly interpreted, is the most impressive record of Pleistocene pluvial climate that the writer has been able to discover in the desert regions of the eastern Mediterranean (Wright 1956). It is hoped that

additional investigations of these interesting features will lead to further information about their significance and time of formation.*

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* Subsequent to the preparation of this manuscript, a paper by Evenari and Koller has appeared in the Scientific American, v. 194, p. 39—45, 1956, in which somewhat similar features in the Negev, south of the Dead Sea, have been ascribed to irrigation practices of the Nabateans, who inhabited that area about 2000 years ago. Although the air photograph reproduced in the article shows striking similarities to the photographs in the present paper, the Negev stripes differ in being straight and clean. They show neither the gentle arcuate form or the consistent downstream curvature that is found at the ends of the Syrian stripes. Other than the stone rings already mentioned, no indications of intensive habitation were found in the Syrian area—no canals, cisterns, stone walls, stone piles, or other structures apparently associated with the striped wadis in the Nabatean area. If the Syrian stripes represent artificial structures which disrupted the natural waterflow in the wadis, it seems unlikely that they would have survived the thousands of years since abandonment without being breached by natural channel flow. They appear to be in equilibrium with the modern hydrologic conditions. The region should be re-examined, however, in the light of this alternative hypothesis.

Figure 1

Air photograph of transverse vegetation stripes on wadi floors, near Rutba, western Iraq, in Wadi Hauran drainage. Note asymmetry of dark stripes and consistent downstream curvature of stripes at margins. Scale can be estimated from the desert road.

Figure 2

Excavation across "boil". Note lack of stones in "boil" compared to adjacent trough.

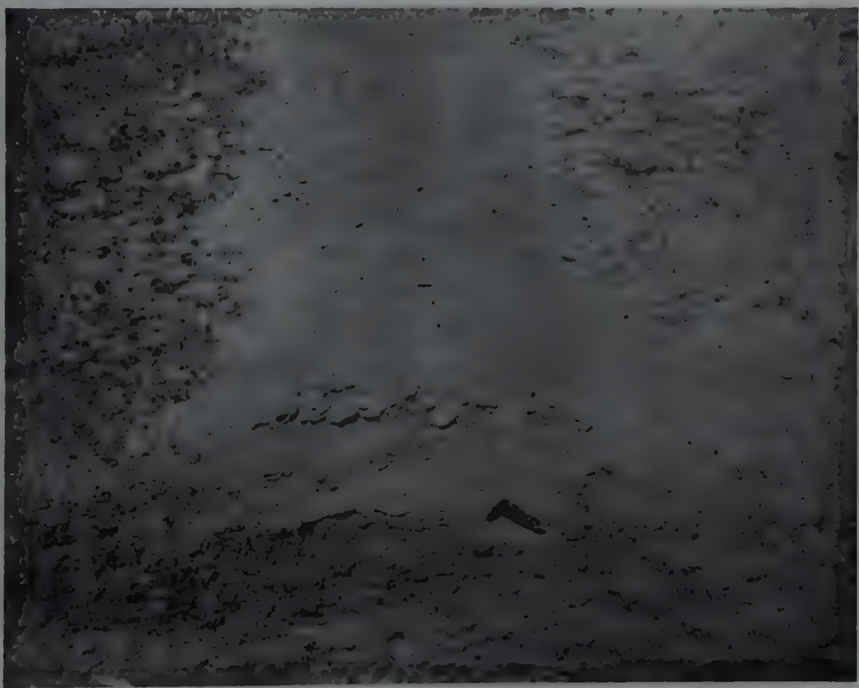

Figure 3

Dark vegetation stripes bordered on upstream side by linear "boil" (with shovel).

A NEW BELEMNOID GENUS FROM THE PALEOCENE OF ISRAEL
WITH REMARKS ON THE CLASSIFICATION OF THE TERTIARY DIBRANCHIATE CEPHALOPODS

M. AVNIMELECH
The Hebrew University of Jerusalem

ABSTRACT

Two specimens of belemnoid rostra found in Paleocene marls in southern Israel were assigned to a new genus, *Belocurta* Avnimelech, represented by a new species *B. yahavensis* Avnimelech. This species is probably the oldest known type of tertiary belemnoid. General consideration leads to some changes in their classification.

INTRODUCTION

A group of geology students of The Hebrew University of Jerusalem, has collected numerous teeth and bone fragments of fishes and reptiles in an area near Ein Yahav (Ein Weiba) on the western side of Wadi Araba, Israel, appr. 50 km south of the Dead Sea, where a marly phosphatic formation of Campanian age occurs, covered by Danian ("Ghareb") and Paleocene ("Taquiya") marls.

Among the collected remnants of fishes and reptiles two specimens of belemnoid rostra have been revealed. The unusual shape of these rostra arouses considerable interest on account of their stratigraphical position and their phylogenetic significance. Both specimens are similar, belonging certainly to the same genus but different in some details, so that a possibility arises that they belong to different species or that the morphological differences are due to sexual dimorphism. No known genus fits our fossils and therefore a new genus, *Belocurta* Avnimelech, is herein created.

SYSTEMATIC DESCRIPTIONS

Order : *BELEMNOIDA*

Genus *Belocurta* Avnimelech

Genotype: *Belocurta yahavensis* Avnimelech, n. sp.

Diagnosis. Belemnoid, known as yet by rostrum only. The rostrum short and broad: in the two known specimens 15 and 18 mm long and at the anterior end 11—14 mm broad; rounded in cross-section, with blunt rounded ending, with no epirostrum; the apical angle of the rostrum appr. 30° — 40°; alveolus broad, shallow, triangular in shape at its borders; ventral front broadly rounded, similarly

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rounded are the two lateral ribs of dorsal side; capitulum not much pronounced with shallow sinus at the border; the broad dorsal border deeply incised in its midst, thus forming in the rear two symmetrical wing-like extensions, the border of the dorsal incision is irregularly denticulated; the inside of the alveolus is vaguely reticulated, the reticulation being formed by shallow, faint radial ribs, ascending from the bottom of the alveol, crossed by very thin lines; the incision of the dorsal border probably corresponds to the basis of proostracum.

DISCUSSION

The genus is known as yet in two specimens only from the Paleocene of Israel. Its significance will be discussed later. Of all the known genera *Belocurta* seems to be nearest the genus *Spirulirostridium* from the Lower Oligocene of Tyrol, but it differs chiefly by having the dorsal wing-like lateral extensions at the upper end of the rostrum; in the other genera — *Belemnosis, Belopterina, Belopteridium* and *Belopterella* — the rostrum is more or less irregularly club-shaped, is exceedingly longer and its alveolus definitely deeper; the genus *Belosepiella* is entirely different, with the rostrum reduced to some sort of a protective shield. Our limited knowledge about the tertiary belemnoids does not allow us to speculate reasonably about the phylogenetic relationship of the quoted genera.

The "Taquiya" marls from which the *Belocurta* specimens most probably derive, contain foraminiferal fauna of Paleocene as well as that of Danian age and the fish and reptilian remnants are also partly of transitional type. The presence of such a form like *Belocurta* is rather in favour of Paleocene age.

Derivation of name. — *Belos,* Gr., dart; *curtus,* L., short; referring to the general shape of the rostrum.

Belocurta yahavensis Avnimelech, n. sp. (Figures 5-8)

Rostrum very short and broad (15 mm long, 11 mm broad, its angle appr. 40°; alveol shallow, with sharp borders, triangular in cross-section; dorsal incision broad but not very deep; the dorsal border irregularly denticulated; the "wings" of the dorsal side outwardly sharply pointed.

Holotype : Preserved in the collections of the Department of Geology, The Hebrew University of Jerusalem.

Occurrence — Type locality: "Thousand Teeth Locality", near Ein Yahav, Araba valley, appr. 50 km south of the Dead Sea, Israel, coord. 167/003.

Belocurta yahavensis forma *oblonga* (Figures 1-4)

This fossil remnant differs from the former, being relatively narrower (apical angle appr. 30°, length 18 mm, width 13 mm); its alveolus, which is damaged on the ventral side, is shallower and its borders are not sharp but obtuse and straight; the dorsal incision is relatively narrow and deep; the "wings", which are damaged as well, seem to be longer and narrower.

This form is supposed to represent male individiuum of the former species.

Holotype: Coll. of the Department of Geology, The Hebrew University of Jerusalem.

Occurrence: as above.

GENERAL CONSIDERATIONS

As pointed out above it is difficult to find the proper relatives of the new genus among the known tertiary genera. One of the causes of this difficulty is the questionable definition of the genera as well as the vague limitation of the higher taxonomic units.

The classification of the tertiary belemnoids lacks general agreement and changes greatly from author to author. Even the subdivision into the suborders of Belemnoidea and Sepioidea is not well defined so that it almost loses its theoretical and practical significance. On the basis of the shape of the rostrum and of the phragmocone — which expresses several anatomical and functional characters — three main groups may be defined. The first group, including few genera, with decidedly straight phragmocone and with long rostrum and deep alveolus, seems to be nearly relative to the cretaceous belemnites; the genera of this group are known to occur in the Eocene. The other group embraces belemnoids with more or less bent phragmocones and with correspondingly much shorter rostra, which are usually blunt, obtuse and often irregularly bulbous; it is represented by more numerous genera and its stratigraphical range is wider: from Paleocene up to Lower Oligocene. The third group is derived, no doubt, from the former one and is characterized by sharply pointed, short or relatively long, rostra.

According to these principles the following emendation of the classification of the tertiary belemnoids is proposed:

1. Fam. *NEOBELEMNITIDAE* Pavlov 1913 (emend.).

Tertiary belemnoids, probably direct descendants of Cretaceous belemnites, characterized by long, straight rostra with deep alveolus. Eocene.

Genera: *Bayanoteuthis* Munier Chalmas 1872. Eocene.
Styracoteuthis Crick 1905. Eocene.
Vasseuria Munier Chalmas 1880. Middle-Upper Eocene.

2. Fam. *BELEMNOSISIDAE* Avnimelech, n. fam.

Tertiary belemnoids with short, obtuse rostrum and more or less bent phragmocone. Paleocene — Lower Oligocene.

Subfam. *BELEMNOSISINAE* Avnimelech, n. subfam.

Genera: *Belemnosis* Edwards 1849. Eocene.
Belopterina Munier Chalmas 1872. Lower Eocene.
Belopteridium Naef 1922. Lutetian.
Belopterella Naef 1922. Montian.
Spirulirostridium Naef 1921. Lower Oligocene.
Belosepiella Alessandri 1905. Midddle Eocene.

Subfam. *BELOPTERINAE* Avnimelech, n. subfam.
Rostrum laterrally alate. Eocene—Lower Oligocene.
Genus *Beloptera* Deshayes 1824. Lower Eocene—Lower Oligocene.
Genus *Belocurta* Avnimelech 1956. Paleocene.

3. Fam. *SPIRULIROSTRIDAE* Naef 1921 (emend.). Belemnoids, the rostra of which are prolonged in a more or less distinct point. This family seems to be nearest to *Sepioidae*. Eocene–Miocene.

Genera: *Belemnosella* Naef 1922. Eocene.
Spirulirostra d'Orbigny 1842. Eocene-Miocene.
Spirulirostrella Naef 1921. Lower Oligocene.
Spiruliorostrina Canavari 1892. Miocene.
Belosepia Voltz 1830. Eocene.
Stenosepia Vincent 1901. Eocene.

This proposed rearrangement of tertiary belemnoid genera illustrates well their evolutionary trends; the *Neobelemnitidae*, externally nearest to the mesozoic genera are confined to Eocene alone; the *Belemnosisidae*, with characteristically obtuse rostrum, range from Paleocene to Lower Oligocene; the *Spirulorostridae*, which are equipped with pointed epirostrum, begin in Eocene but are present mainly in Miocene, thus linking with the mainly Neogene family of *Sepiodae*.

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I am indebted to Miss R. Strassburger for her able and exact drawing of the fossils.

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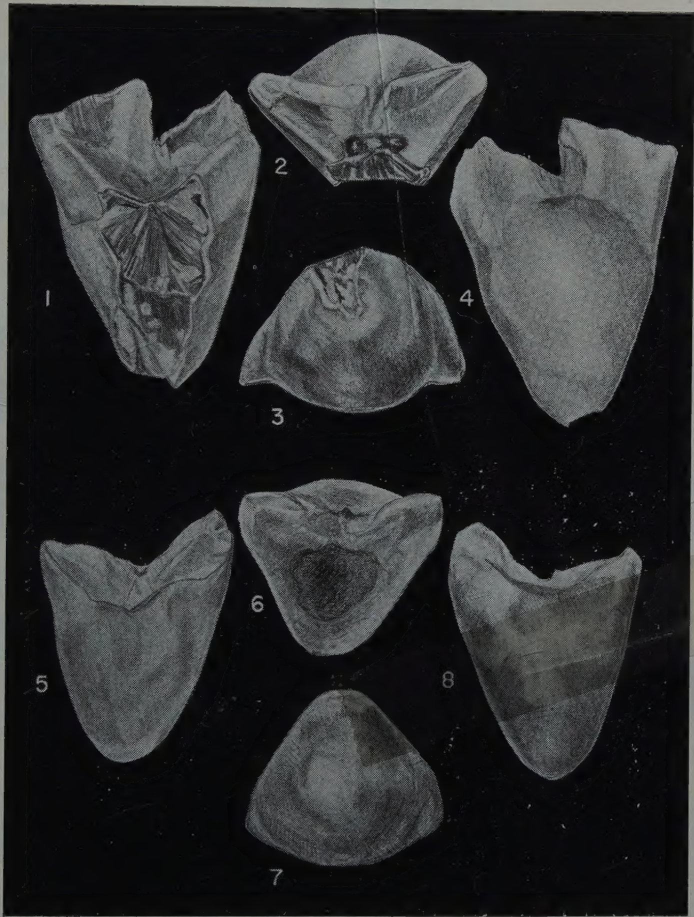

Figures 1-8

1-4: *Belocurta ?yahavensis* Avnimelech, forma oblonga. Holotype.
1. ventral, 2. alveolar, 3. posterior, 4. dorsal view

5-8: *Belocurta yahavensis* Avnimelech n. sp. Holotype.
5. ventral view, 6. anterior, alveolar view, 7. posterior view, 8. dorsal view.

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